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STATE GEOLOGICAL SURVEY OF KANSAS

RAYMOND C. MOORE, State Geologist

Bulletin no. 5

ELK CITY GAS FIELD

Elk and Montgomery Counties, Kansas

BY

CHARLES W. BOUGHTON

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BULLETIN 5

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ELK AND MONTGOMERY COUNTIES, KANSAS

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LETTER OF TRANSMITTAL.

Dr. Frank Strong, Chancellor of the University of Kansas, ex officio Director of the State Geological Survey:

SIR—The natural gas deposits of Kansas comprise one of the most important of its natural resources. At the present time, when the problem of fuel supply has been acute, it is desirable to learn the conditions under which natural gas is found in the state and to determine as definitely as possible what may be the future supply.

The present report on the Elk City gas field, by C. W. Boughton, describes one of the important gas-producing districts in southeastern Kansas. It will constitute Bulletin 5 of the Reports of the State Geological Survey of Kansas.

Respectfully submitted.
RAYMOND C. MOORE,
State Geologist.

TABLE OF CONTENTS.

PAGE

INTRODUCTION 9
- Location 9
- Topography and drainage 9
- Field work 9
- Acknowledgments 9

STRATIGRAPHY.
- Exposed rocks 11
  - Pennsylvanian system 11
    - Douglas formation 11
      - Lawrence shale 11
      - Iatan limestone 11
      - Weston shale 11
  - Quaternary deposits 12
- Rocks not exposed 12
  - Pennsylvanian system 12
    - Lansing formation 12
      - Stanton limestone 12
      - Vilas shale 13
      - Plattsburg limestone 13
    - Kansas City formation 13
      - Drum limestone 13
    - Marmaton formation 13
      - Fort Scott limestone 13
    - Cherokee shale 13
  - Mississippian system 14
  - Sandstones 14
    - Wayside sand 14
    - Weiser sand 14
    - Bartlesville gas sand 15
    - Other sandstones 15

STRUCTURE.
- Surface structure 16
- Subsurface structure 18
- Bartlesville sand 19
- Relation of structure to production 19
- Surface of the Mississippian limestone 19
- Convergence of the strata 21

PRODUCTION.
- History of the field 21
- Present development 21
- Gas marketed 23
- Pipe lines 23
- Compressor station 25

PROBABLE LIFE OF THE FIELD.
- Water conditions 25
- Pressure decline 26
- Method of determining probable future production 27
- Future development 28

PPENDIX 29

ILLUSTRATIONS.

PLATE I. Flood plain of Elk river, together with compressor station.
PLATE II. Structure and production map.
PLATE III. Structure of the producing gas sand.
PLATE IV. West No. 5, immediately after touching the gas sand.
PLATE V. West No. 2, immediately after being drilled in, and wreckage of rig on West No. 5 after well was brought under control.

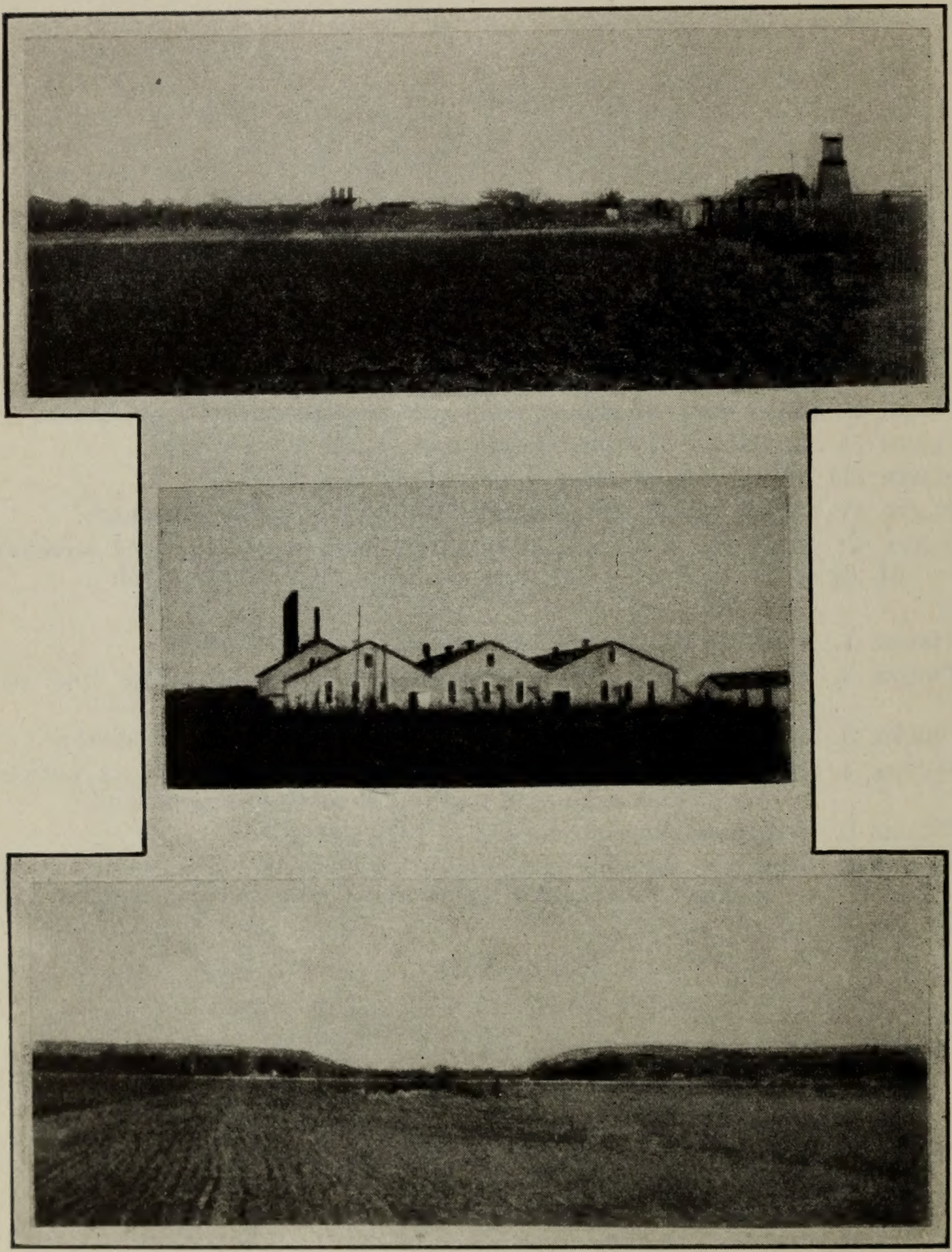
FIGURE 1. Detailed vertical section of the exposed sediments.
FIGURE 2. Skeleton map showing the combined and average open flow capacity of gas wells.
FIGURE 3. Skeleton map showing depth of Mississippian limestone.
FIGURE 4. Isopachous contour map of thickness of sediments between Fort Scott limestone and top of producing gas sand.
FIGURE 5. Diagram showing decline in rock pressure.
FIGURE 6. Diagram showing comparative decline in rock pressure in important southeast Kansas and Oklahoma gas fields.

ERRATA

Figure 2, page 16, and Figure 4, page 20 should be interchanged, the titles remaining as they are.

Result of calculation on page 28 should read 18,000,000,000 cubic feet.

PLATE I.



Views along the flood plain of Elk river, together with compressor station in section 26.

THE ELK CITY GAS FIELD.

MONTGOMERY AND ELK COUNTIES, KANSAS.

By Charles W. Boughton.

INTRODUCTION.

LOCATION.

THE Elk City gas field is located in township 31 south, range 13 east, in the northwest part of Montgomery county and the contiguous portion of southeastern Elk county. It lies midway between the towns of Elk City and Oak Valley. The Winfield branch of the Atchison, Topeka & Santa Fe Railway and the Independence-Winfield automobile highway run through the field.

TOPOGRAPHY AND DRAINAGE.

The field occupies an area of approximately three and a half square miles, the greater portion of which lies in Montgomery county. The productive area is bordered on the east north, and southwest by wooded hills, 100 to 150 feet high. On the west, Elk river has cut away these hills, and the larger number of the producing wells are on the flood plain of this stream. Two relatively small creeks, which unite a short distance from the river, drain the area from the north.

FIELD WORK.

The examination of the Elk City field was made during the month of November, 1919, by Chas. W. Boughton and P. C. Murphy. A telescopic alidade and plane table were used in mapping the surface geology and structure, and in securing the elevation of the well locations. The elevations were controlled from a Santa Fe bench mark in the north center of section 36. Elevation, 836.2 feet above sea level.

ACKNOWLEDGMENTS.

The writer is indebted to Mr. C. A. Blackburn of the Elk Valley Syndicate, and Mr. V. F. Milton of the Southwestern Gas Company, for much of the field data. Such figures as the pressure decline, and a list of the wells, were supplied by Messrs. W. H. Johnson and M. L. Truby of the Southwestern

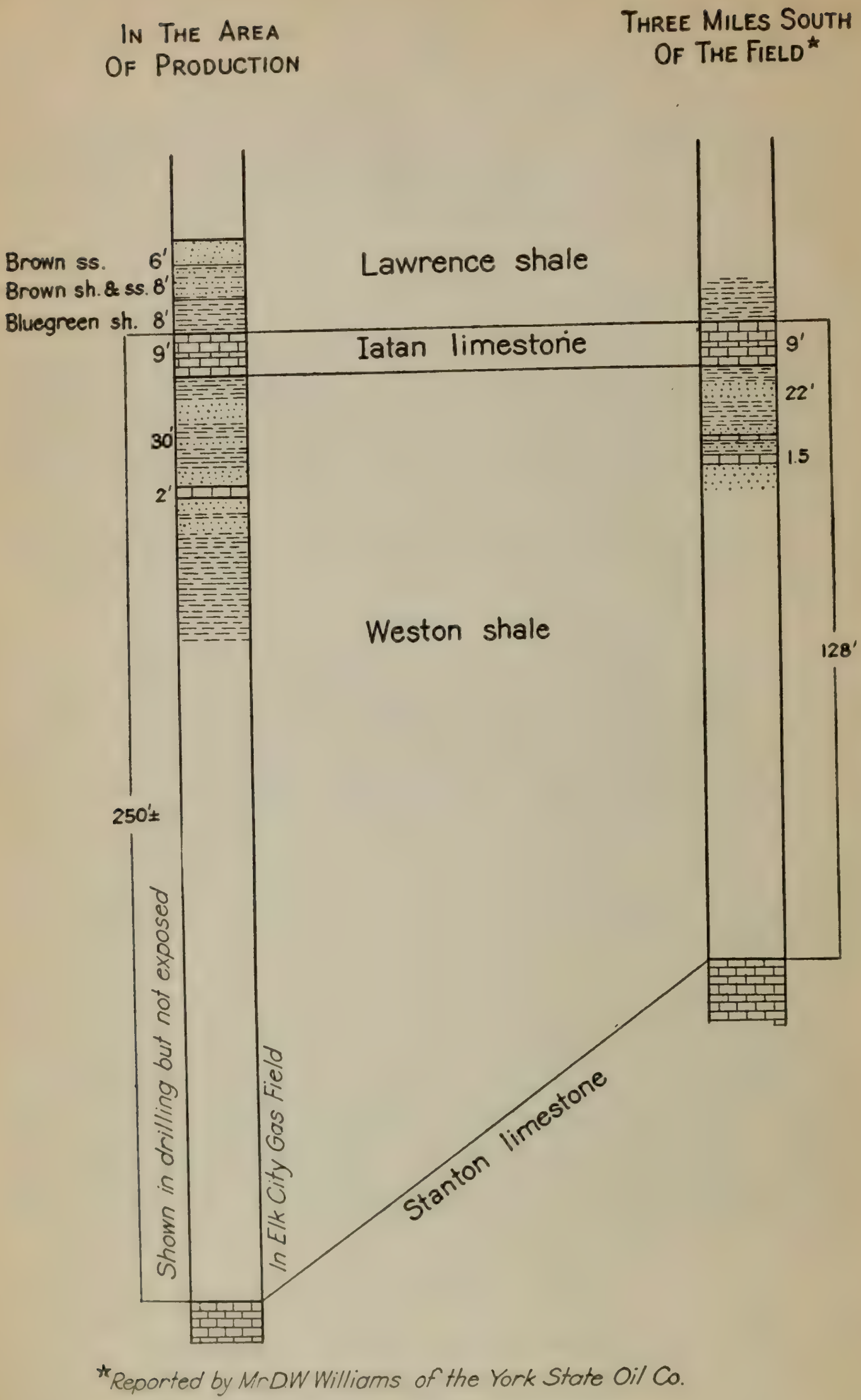


FIGURE 1.

Detailed vertical section of the rocks exposed in the vicinity of the Elk City gas field.

STATE GEOLOGICAL SURVEY OF KANSAS

Copies of Bulletin 7, The Eldorado Oil and Gas Field, by A. E. Fath, prepared in cooperation with the U. S. Geological Survey, have been mailed from Washington. In case you did not receive a copy, please advise and we will furnish duplicate from Lawrence.

Raymond C. Moore,

State Geologist.

Gas Company at Independence. Messrs. E. M. Stryker, M. D. Stryker, and Lester Stryker, of Fredonia, offered many helpful suggestions and in part supplied the data concerning the Mississippi limestone and other gas fields of this region. The writer is indebted to Mr. D. W. Williams of the York State Oil Company, Caney, for a number of well records and for the vertical section south of the producing area. Appreciation of the direction and suggestions of Dr. R. C. Moore is also expressed.

STRATIGRAPHY.

EXPOSED ROCKS.

Pennsylvanian System.

Douglas Formation. The rocks exposed in the Elk City gas field belong to the Douglas formation, one of the middle divisions of the upper Pennsylvanian in Kansas. Of the four members of this formation, the Weston shale, Iatan limestone, Lawrence shale, and Oread limestone, all but the Oread are exposed in the area under consideration.

The hills surrounding the field are capped with sandstones belonging to the Lawrence shale, which constitutes about one-half of the Douglas formation. The Lawrence shale is about 180 feet thick and is composed of alternating beds of dark brown sandstone and shale, the amount of the sandstone being about equal to that of the shale. The Lawrence shale has been mapped from northwest Missouri to north-central Oklahoma, and the ratio of sandstone to shale appears to increase rapidly from north to south in southern Kansas.

The Iatan limestone, which was used as a key bed in mapping the Elk City field, lies directly beneath the Lawrence shale. It varies from four to eight feet in thickness, and although covered in many places by slumping of the overlying shale and sandstone, it makes a fairly easily traceable horizon. On fresh fracture the bed is a dark bluish gray, but it weathers to a light steel color. As a rule, the Iatan is highly fossiliferous, containing many small brachiopods, crinoid stems, some Fusulina, and a considerable amount of vegetable matter.

The Weston shale lies directly below the Iatan limestone, and occupies the lower portion of the hillsides and most of the valley floor. This member is composed of various colored shales and brown sandstones, and contains at least one thin linestone bed. The limestone is found about thirty-two feet below the Iatan, and is quite different from that bed in physical characteristics and fossil content. It is uniformly about twenty inches in thickness, has a dark muddy color, and breaks readily into small irregular-shaped fragments. The contained fossils are for the most part Fusulina, a small number of brachiopods being found. In his sections three miles south of the field, Mr. D. W. Williams* reports another limestone bed, between the Iatan and the bed which has just been described. This limestone is described as thin, sandy, and rather soft. It was not encountered in the area included in this report.

Quaternary Deposits.

The Quaternary deposits in the Elk City field are represented by silt, gravel, and sand deposited on the flood plain and in the bed of Elk river. Some of the wells at present situated a quarter of a mile from the river show deposits of sand and gravel 50 feet in thickness, showing that the stream has at times occupied various portions of the valley.

ROCKS NOT EXPOSED.

Pennsylvanian System.

Information concerning the rocks below the surface is derived largely from well records, and in part from observations noted outside of the producing area. About twenty well records and a fairly complete set of sand records were available. The strata between the Iatan bed and the Mississippian limestones in this region vary in thickness from 1,500 to 1,650 feet. The section consists of about three-fourths shale, 15 per cent limestone, and the remainder sandstone. (See vertical sections, plate II.)

Lansing Formation. The first limestone below the surface throughout most of the field is the Stanton, which is the uppermost member of the Lansing formation. Its nearest surface outcrop is in the bed of Elk river at Elk Ciy. In this region the Stanton has an average thickness of about 50 feet. It is a light gray limestone and rather massive, the beds being separated by thin layers of slaty shale. At the city of Fredonia the interval between the Stanton and the Iatan limestone is about 230 feet.† Three miles south of the field D .W. Williams found it to be but 128 feet. Within the producing area, the interval varies from 200 to 250 feet. These irregularities indicate either a short period of erosion before the deposition of the succeeding strata, or more probably an irregularity in the deposition of the overlying Weston shale. In any case, the top of the Stanton is, in fact, so irregular that it cannot be used with certainty in determining the probable elevation of the Iatan where the latter has been eroded.

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* Personal communication.

† Mr. E. M. Stryker, Fredonia. Personal communication.

The Vilas shale, which underlies the Stanton limestone, thickens toward the south. At Fredonia, 20 miles to the northeast, it is 5 to 15 feet thick,* while the log of Simmons well No. 1, in the northeast quarter of section 27, shows it to be 50 feet thick. At Longton, 25 miles northwest of the Elk City field, the Vilas shale is over 100 feet thick.

The Plattsburg ("Allen") limestone is a highly crystalline bed, rather massive, and contains a variety of fossils. It breaks easily into small angular fragments. At Fredonia this member is 80 and 90 feet thick,* while the Simmons log shows it to be but 5 feet in thickness.

Kansas City Formation. The thickest limestone encountered in any of the logs lies approximately 450 feet below the surface in the center of the field. Some of the well records show as much as 115 feet of massive limestone. This limestone belongs without doubt to the very calcareous Kansas City formation, and probably represents in large part the Drum limestone, which is known to thicken toward the southwest.

Marmaton Formation. The only bed of importance in the Marmaton, from the standpoint of correlation of the well logs, is the Fort Scott ("Oswego") limestone, which lies about 1,100 feet below the Iatan and consists of an upper member of fairly hard white limestone, 22 to 30 feet thick, and a lower bed of blue limestone, 6 to 12 feet thick, the two being separated by 4 to 10 feet of dark shale. A limestone corresponding in position and character to the Fort Scott is encountered in all the wells of the Elk City field.

Cherokee Shale. Although the Cherokee shale, which constitutes the basal portion of the Pennsylvanian series, contains many beds of economic importance, few of its shale and sandstone beds can be traced from one place to another. Practically all the well records in the Elk City field show a bed of "red-rock" 220 feet or more below the Fort Scott limestone. This is probably a firmly-cemented, red-colored shale. It varies in thickness from 6 to 10 feet. Many of the records show two beds of "red-rock," separated by 30 to 40 feet of ordinary shale.

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* Supplied in part by Mr. E. M. Stryker, of Fredonia.

Mississippian System.

The Mississippian limestone, which has generally been considered the limit of possible production in eastern Kansas, has been encountered in a number of wells in this immediate region. (See figure 3.) A typical log, showing the upper part of the Mississippian in the Elk City field, is as follows:*

Drill record of the upper part of the Mississippian in the Elk City district.

1 ft.	Blue limestone, in some cases chert.
1- 3 ft.	Blue shale.
20-30 ft.	Hard gray limestone.
10-25 ft.	Soft porous limestone.
20-35 ft.	White sandstone, containing water, and in some cases gas.

Sandstones.

Wayside Sand. Well logs in the Elk City field show three persistent sandstone horizons. The uppermost of these sands is about 30 feet thick and was encountered at 747 feet in the discovery well. (Simmons No. 1.) In the logs of a few wells this sand has been classified as the Wayside, which is fairly productive about the town of Wayside, 20 miles to the south. For many years wells in this region extended only to this sand, and it was not until the Simmons well was drilled into the deeper gas-bearing sands that it was thought worth while to drill deeper in other parts of the field. A number of small oil wells in sections 34 and 35 apparently secure their production from this shallow sand.

Weiser Sand. Between 70 and 90 feet below the Wayside the records show a second sand, to which the name Weiser has been applied. This sand is rather uniformly 40 feet in thickness and thus far is unproductive in this field. It is possible that this sand corresponds to the Peru sand of Chautauqua county, as both are found at practically the same depth below the Wayside. Mr. E. H. Klinefelter, of the Hale Gas Company, reports that this sand is in all probability the equivalent of the Peru sand, but on account of uncertainty as to this at first, the sand was named after an operator, Mr. Weiser, who first encountered it in Montgomery county.

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* Supplied in part by Mr. E. M. Stryker, of Fredonia.

Bartlesville Sand. The gas sand in the Elk City field lies about 1,350 feet below the surface in the central part of the field. It is known to be at least 24 feet thick, as some of the wells have drilled into it that far. The smallest producing gas well in the field, in the N. W. ¼ of the N. E. ¼ of section 23, drilled through 24 feet of sand and into the Mississippian limestone, so it is possible that wells in the center of the producing area draw from as much as 30 or possibly 40 feet of sand. The sand appears to be uniform in texture and composed of round, medium-sized grains. The interval between the top of the gas sand and the Fort Scott limestone varies from 319 to 370 feet. (See figure 4.) Considering this interval, the sand appears to be in the horizon of the Bartlesville sand, which is so highly productive in northeastern Oklahoma. On the other hand, the well mentioned above, which drilled through the sand into the Mississippian, found but two feet of black shale between the base of the producing gas sand and the top of the Mississippian limestone, which would correspond to the position of the Burgess sand. Along the southern border of Montgomery county the Bartlesville sand is known to be about 100 feet above the Mississippian, while the Burgess lies directly upon the limestone. A study of the log of Lewis No. 1, mentioned above, shows but 375 feet of Cherokee shale between the Fort Scott and Mississippian limestones, while the log of Spaht No. 1 (in the southeast corner of section 24) shows 455 feet of shale. For this reason, it is believed that the producing gas sand in the Elk City field should be correlated with the Bartlesville.

Other Sandstones. The sand found in Spaht No. 1 lies directly upon the Mississippian. It is approximately 435 feet below the top of the Fort Scott limestone, and 35 feet below the horizon of the Bartlesville sand. A fifth sandstone horizon exists a few feet above the Fort Scott, while a sixth is found directly below this limestone. Neither of these sands is persistent, or has been found to contain commercial deposits of oil or gas. Both vary considerably in thickness.

The terms Wayside, Weiser, Bartlesville, and Burgess are applied to sandstones within certain horizons, and although they may be of approximately the same age it is highly improbable that they represent one continuous sand body.

STRUCTURE.

SURFACE STRUCTURE.

The structure of the surface formations in the Elk City gas field is graphically indicated on plate II by means of ten-foot contours, which show the elevation of the Iatan limestone above sea level. It may be noted that the surface in general dips to the west about 35 feet in a mile. Superimposed on this broad monocline are two small domes, each with a relief of approximately 20 feet. The smaller of these domes is located in the north-center of section 23, while the larger covers the southeast quarter of the same section.

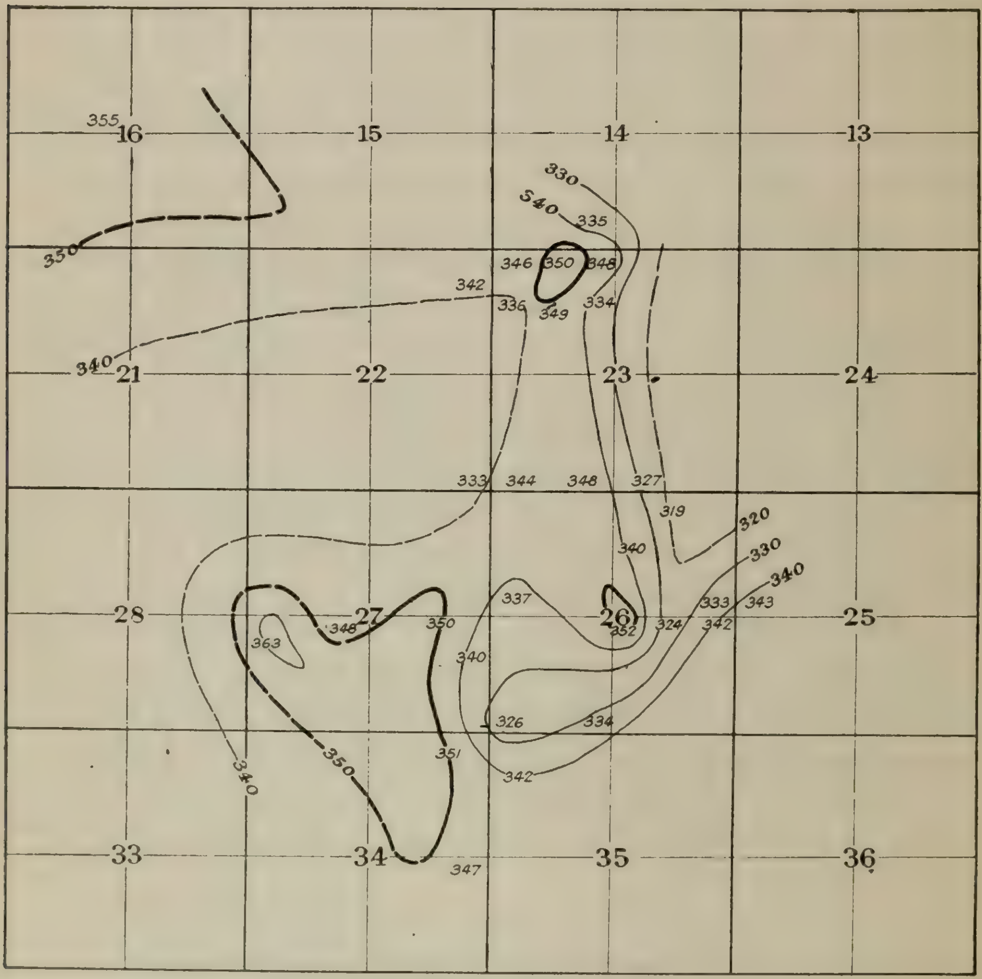
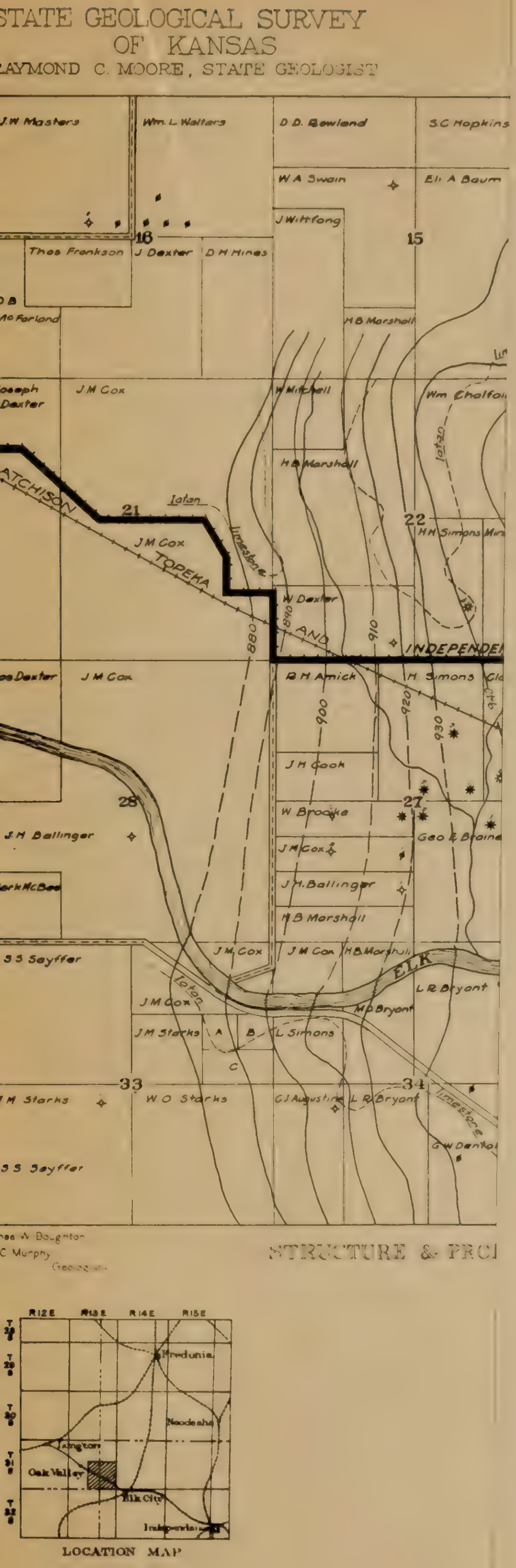


FIGURE 2.

Map showing the total and average initial open flow capacity of the gas wells in each quarter section.

Structure a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J M Cox
W Mitchell
Wm Chalfant
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W Brooke
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J M Cox
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ELK
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Iatan
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L Simons
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J M Starks
W O Starks
C J Augustine
L R Bryant
Limestone
G W Denton
S S Seyffer
Chas W Boughton
C Murphy
Geologists
STRUCTURE & PRO
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Fredonia
Neodesha
Longton
Oak Valley
Elk City
Independence
LOCATION MAP

PLATE II.

Structure and production map of the Elk City gas field.

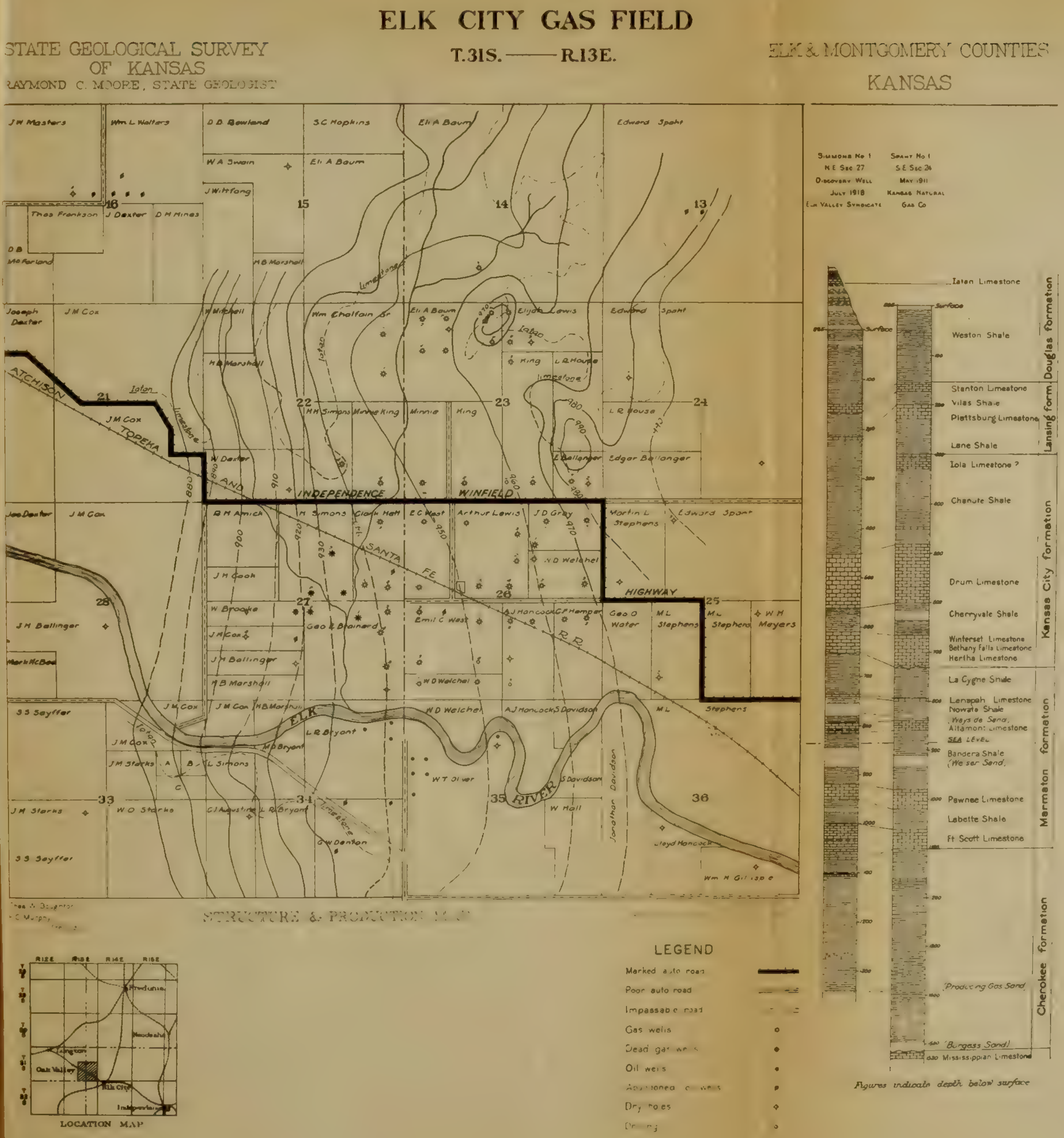
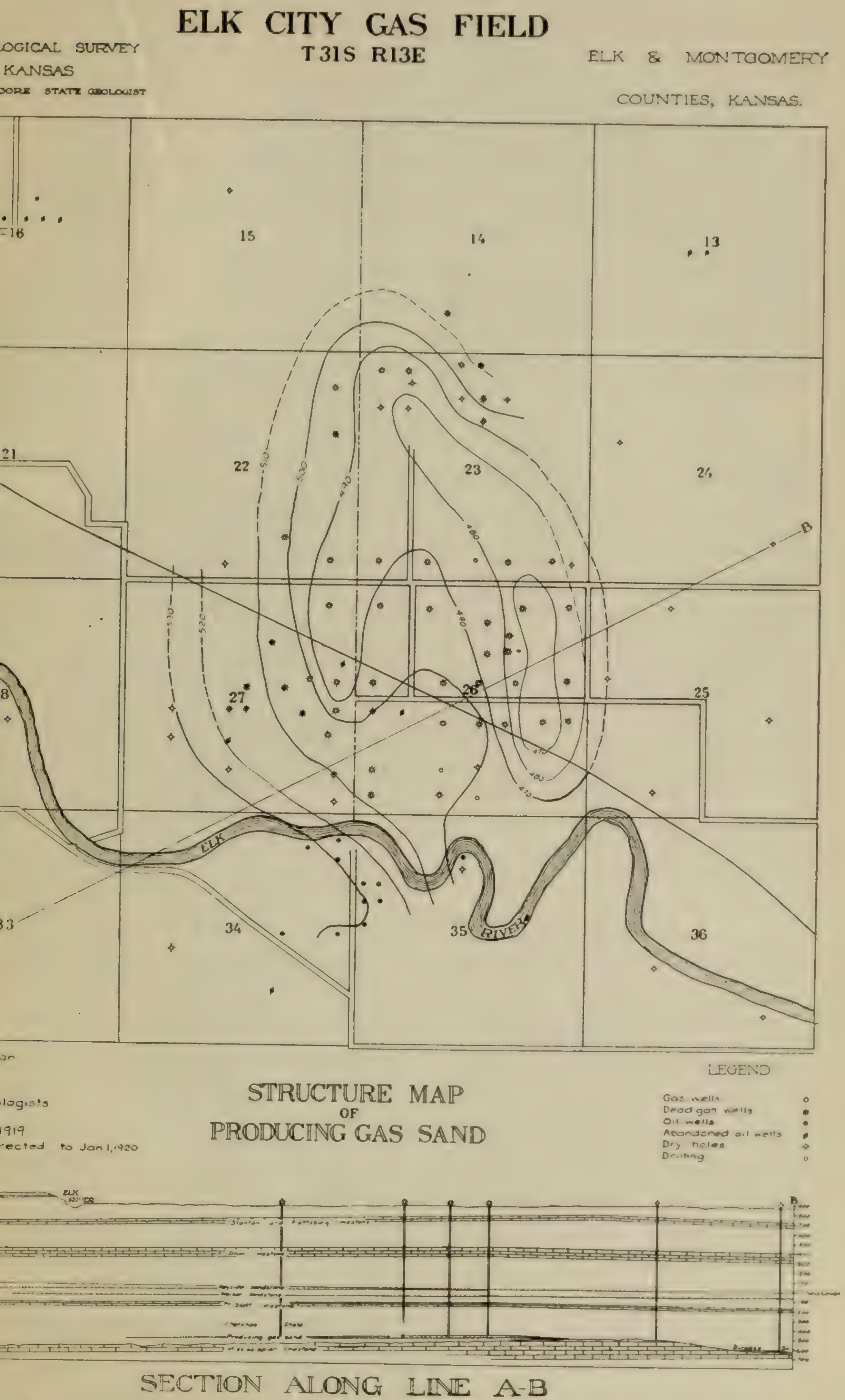


PLATE III.



Structure map of the producing gas sand in the Elk City field.

SUBSURFACE STRUCTURE.

The Iatan limestone has been eroded away from the southeastern and central parts of the Elk City field, and on account of the uncertain interval between the Iatan and Stanton limestone in this area, the latter cannot be used with certainty in determining the probable elevation of the Iatan. However, a study of well records from sections 23, 24, 25, and 26 shows approximately 25 feet of east dip on the Stanton, Drum, and

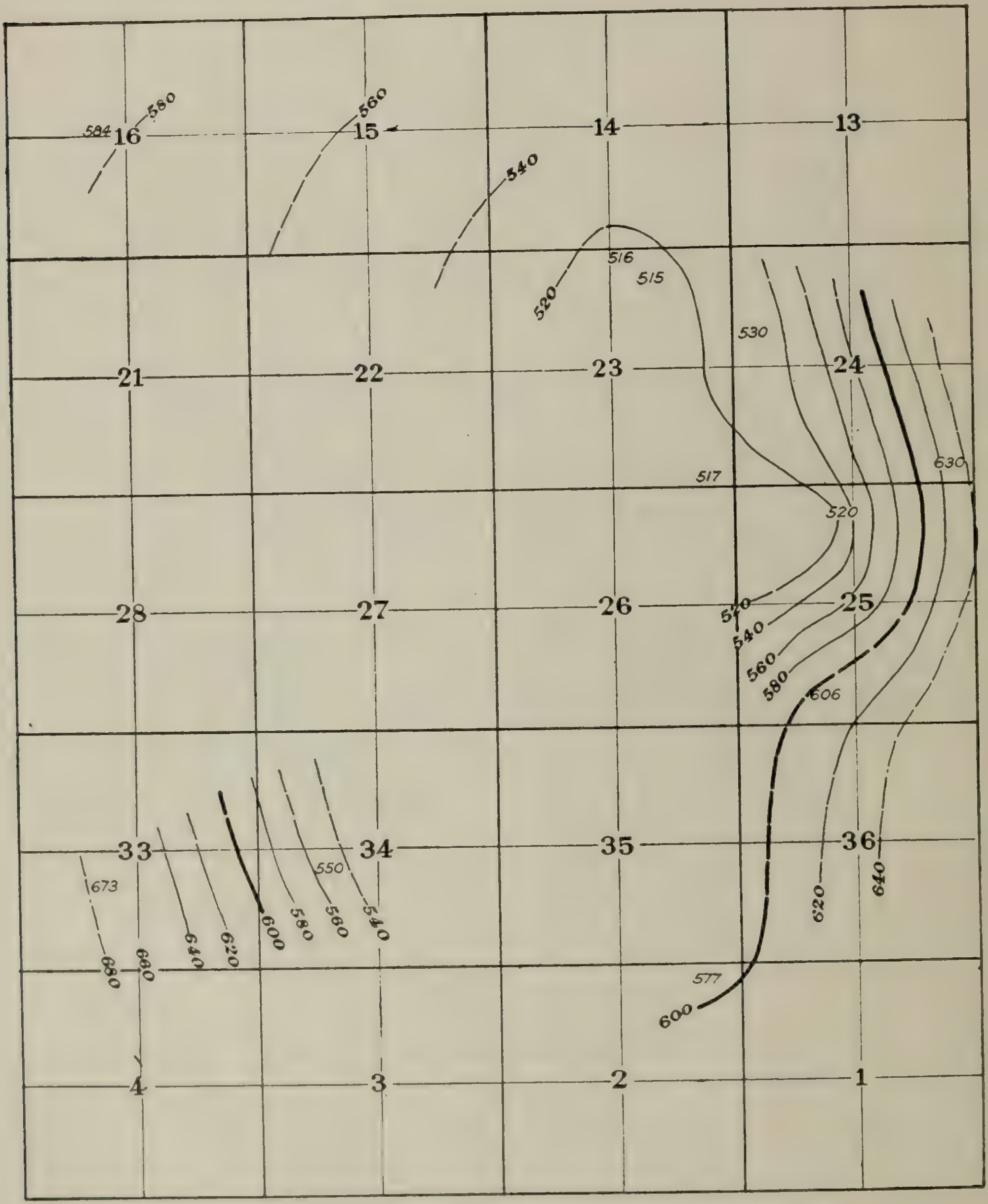


FIGURE 3.

Skeleton map showing the depth of the Mississippian limestone below sea level. Contour interval is twenty feet.

ort Scott limestone. (See cross section on plate III.) This ast dip extends from the vicinity of the surface domes to the ast side of section 24.

BARTLESVILLE SAND.

Contours for plate III, which shows the depth of the top of he Bartlesville gas sand below sea level, were determined by omparing the elevation of the mouth of the wells with their and records. This map shows that the highest part of the and lies in sections 23 and 26, and that the dip is to the outh and west, somewhat the same as that of the surface ormations. It is to be noted that the structure of the sand oincides with that of the subsurface formations, as shown in he cross section.

RELATION OF STRUCTURE TO PRODUCTION.

According to the anticlinal theory, wells of largest ca- acity might be anticipated near the crest of such structures s shown on plate II. Figure 2 shows the combined open flow apacity and the average capacity of the gas wells in each uarter section, and demonstrates that the wells of largest apacity are considerably down the dip from these two small omes. By comparing figure 2 and plate II, it may be noted at there is also little relation between the structure of the as sand and the average capacity of the wells. Indeed, the ells of smallest capacity are found slightly east of the highest art of the producing sand. We must conclude that the tex- ure and porosity of the sand are very important factors gov- rning production.

SURFACE OF THE MISSISSIPPIAN LIMESTONE.

The depth of the Mississippian limestone below sea level, reported in eleven wells in the Elk City field, is shown on gure 3. It is apparent that the Mississippian is 113 feet gher in section 23 than in the southeast corner of section 24, mile to the east. With the data at hand, it is impossible to termine whether these high points of the Mississippian rep- sent an erosional outlier or the crest of a small but rather onounced fold. The cross section shows that the highest rt of the Mississippian directly underlies the crest of the parent folding in the Pennsylvanian strata. It is apparent at folding during Pennsylvanian time would affect the ississippian strata, so at this time the exact structure of the Mississippian cannot be determined. This marked difference in the surface of the Mississippian limestone may be due to pre-Pennsylvanian erosion, to folding during late Mississippian time, or to both. There is between 70 and 80 feet more Cherokee shale in the southeast corner of section 24 than on top of the limestone, which indicates that the irregularity in the surface of the Mississippian existed before Pennsylvanian time.

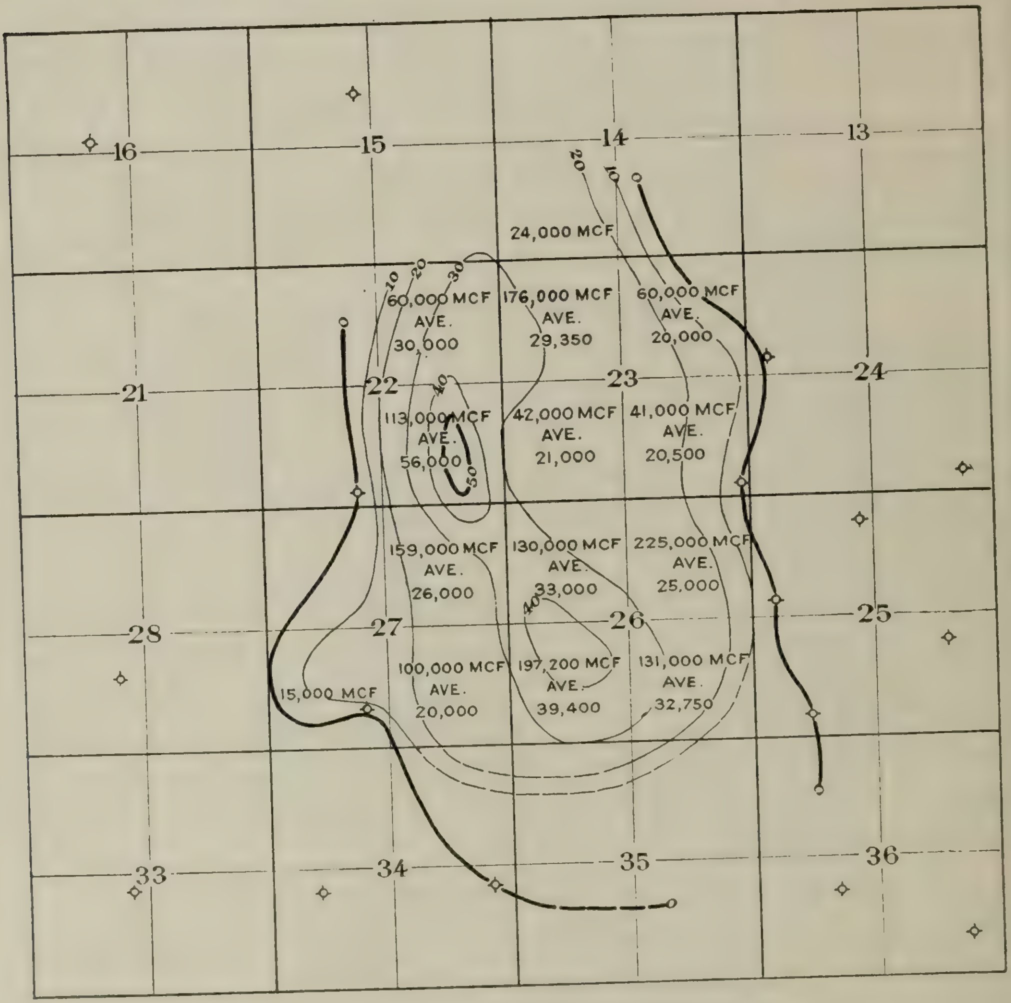


FIGURE 4.

Isopachous contour map showing the thickness of the strata between th Fort Scott limestone and the top of the producing gas sand. Contou interval is ten feet.

It has been suggested that the apparent folding in th Pennsylvanian strata is the result of deposition over thi Mississippian irregularity, but it hardly seems likely that ographic dome could be reflected through 1,500 feet of liments without considerable variation in the thickness of Pennsylvanian strata.

CONVERGENCE OF THE STRATA.

It is interesting to note, as shown by the lines of equal thick-ss (isopachous contours) for the strata between the Fort ott limestone and the top of the producing sand, that a rked convergence of the beds exists (figure 4). In gen-l, the convergence of these beds is toward the north-center section 26. On the other hand, a study of the strata be-een the Iatan and Fort Scott limestones shows a conver-nce toward the northwest corner of section 23.

PRODUCTION.

HISTORY OF THE FIELD.

The first gas well in the Elk City field was drilled July 12, 18, by the Elk Valley Syndicate on the Simmons farm in the rtheast quarter of section 27. The original open flow ca-city was 10,000,000 cubic feet. Previous to that date a mber of wells had secured a small production of oil from Wayside sand at a depth of 750 to 800 feet. In the spring 1911 the Kansas Natural Gas Company drilled a deep test the Spaht ranch, near the southeast corner of section 24, d found 20 feet of dry sand. The second gas well in the ld was drilled in August 5, 1918, on the Simmons land, feet west of the discovery well. It is reported that almost mediately after the drill touched the sand, the gas broke ough with a roar that could be heard several miles. The ginal volume of this well was 32,000,000 cubic feet, and pressure was so great that the well was not shut in for arly a week, and only then with considerable difficulty. Ef-ts to cap the well were futile, and the gas was mudded by means of mud pumps.*

PRESENT DEVELOPMENT.

Up to the present time (December 20, 1919) 52 producing s wells have been drilled in the Elk City field. These wells ge in original volume from 1,500,000 to 86,000,000 cubic feet gas daily, the average being close to 27,000,000 cubic feet. this respect, it is probable that the Elk City field is one of the

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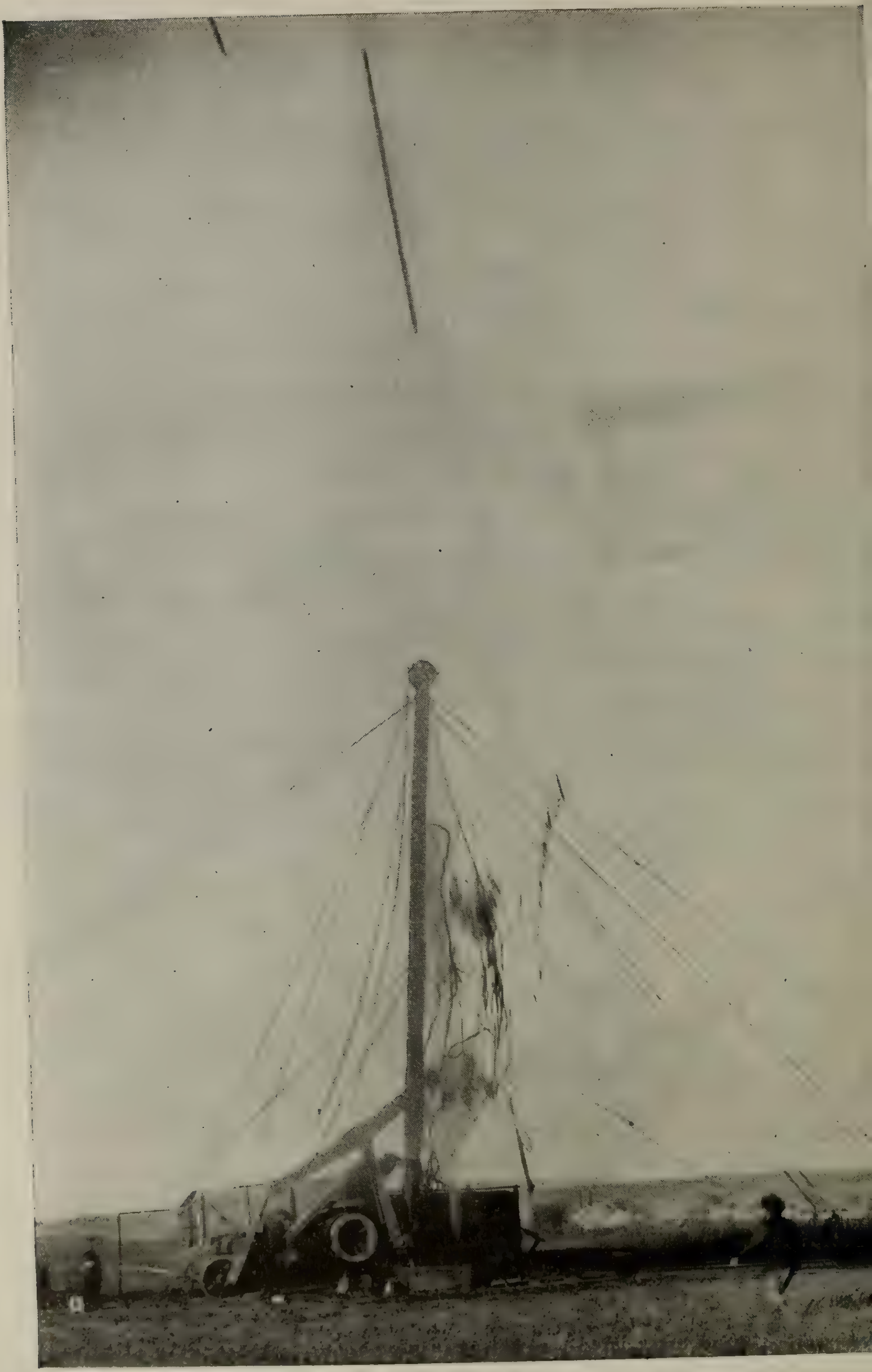
* Oil and Gas Journal. November 21, 1919. Page 80.

PLATE IV.



West No. 5 immediately after touching the gas sand, showing the eff
of the rock pressure.—Courtesy of Southwestern Gas Company.

rgest in the United States. About fifteen dry holes have been illed, determining fairly definitely the extent of the produc- g area. The ratio of dry holes to producing gas wells is less an one to three. A list of wells, showing initial capacity, :., is given in "Appendix A."

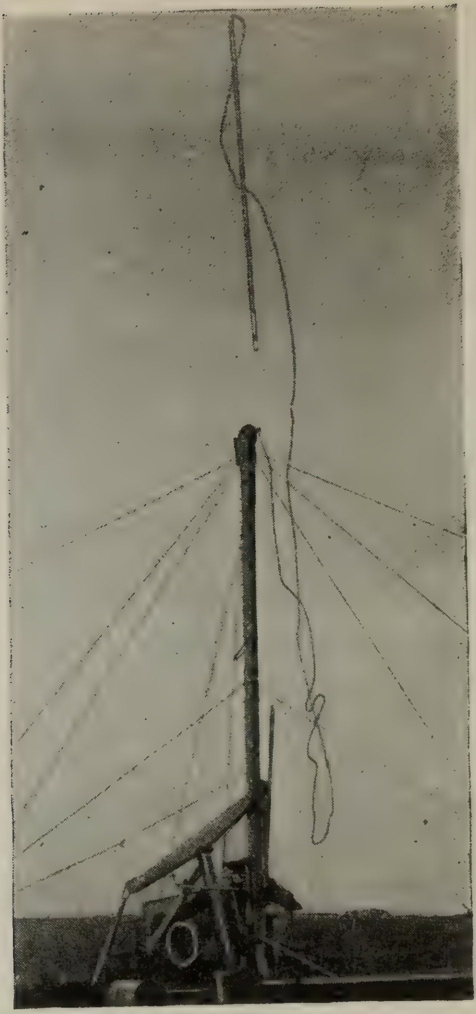
GAS MARKETED.

The Southwestern Gas Company of Independence marketed e first gas from the Elk City field in December, 1918. Up to nuary 1, 1920, the Southwestern had marketed slightly over billion cubic feet of gas, the daily average ranging from)00,000 to 27,700,000 cubic feet. It was impossible to secure y figures on the amount of gas marketed by the Nicholson pe Line Company, although it is reported that their average ily run since July 1, 1919, has varied between 7,000,000 and ,000,000 cubic feet. Assuming that the Nicholson interests arketed on the average about 8,000,000 cubic feet of gas ily, it appears that up to January 1, 1920, their total would be out one and a half billion cubic feet. Although it is im- ssible, with the data at hand, to determine the exact amount gas taken from the Elk City field, it is believed that at least ven and a half billion cubic feet had been marketed up to nuary 1, 1920. (See "Appendix B.")

PIPE LINES.

At present three pipe lines carry the gas from the Elk City ld. The Southwestern Gas Company of Independence has an inch line leading from the field to Grabham station, south of dependence, where it delivers gas to the Kansas Natural Gas mpany. All of this gas, amounting to about one-half of the ily output of the field, is used for domestic purposes. The uthwestern also has a 10-inch line leading to Cherryvale, th a spur line running south to Independence. This line dinarily carries about one-fifth of the daily output, and sup- ies both domestic and industrial consumers. The remaining e is owned by the Nicholson Pipe Line of Kansas City, Mo. is line runs northeast from the field to Lafontaine and odesha, where a considerable portion of its load is used by e Standard Oil Refinery.

PLATE V.



Upper photograph shows West No. 2 immediately after being drilled in. Lower view shows the wreckage at West No. 5, after the well wa brought under control.—Courtesy of Southwestern Gas Company.

COMPRESSOR STATION.

The Southwestern Gas Company has erected a large com-
essor station in the northwest quarter of section 26, which
ill be used to force the gas through the lines when the pres-
re falls to a point where the gas will not flow under its own
essure. This compressor station is now being used to gather
s from the low pressure fields of Chautauqua and Elk coun-
es.

PROBABLE LIFE OF THE FIELD.

WATER CONDITIONS.

During the early history of the Elk City field, when little was
own regarding subsurface conditions, considerable difficulty
s experienced by some operators because they failed to use
fficient casing. With the great pressure found in this pool,
e casing must be absolutely tight and should extend all the
y to the producing sand. Some operators have called this
ld a "water-pressure pool," meaning that the producing sand
lenticular and that the gas is held under pressure by water
ound the edges of the sand body. Such being the case, it
uld be expected that wells around the edge of the producing
ea would suffer from water troubles, and that as the pres-
re declines, the water would become more troublesome to-
rd the center of the pool. In December, 1919, six wells were
sconnected from the pipe line because of water troubles. Re-
rring to plate II, it may be noted that these wells were 1, 2,
d 3 on the Simmons farm, 1 and 2 on the Brainerd, 1 on the
ooke. It was reported that the Simmons wells were to be
eaned and re-tubed in an effort to exhaust the water and se-
re a further production of gas. Brainerd No. 1 is reported
dead. Brainerd No. 2 was troubled with water and a slight
ount of oil, but it was hoped that the well could be cleaned,
-tubed and turned into the low-pressure line of the South-
estern Gas Company. Well No. 1 on the Brooke farm became
oked with water in January, 1919, and it is doubtful if it
ll again produce gas. When water was at first noted in the
ells, attempts were made to plug the bottom of the holes with
rious kinds of material. In some of the wells lead plugs were
ed, and in others a mixture of iron shavings and cement, but
ither of these remedies proved of any value because of the
ck pressure. At present the wells are blown every two weeks,

so as to force out the water, which filters in through the san and which would soon ruin the wells, if permitted to remain i the hole.

PRESSURE DECLINE.

The original rock pressure in practically all of the first well drilled in the Elk City field was 520 pounds. This remaine constant until December, 1918, when the first gas from th field was marketed by the Southwestern Gas Company. Fro

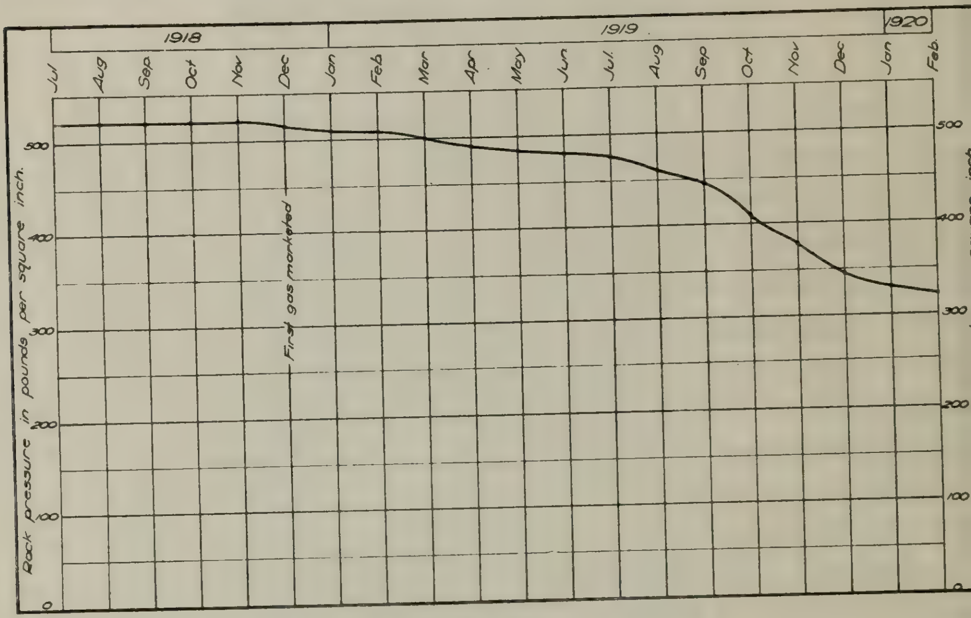


FIGURE 5.

Diagram showing the monthly decline in rock pressure, as measure in pounds per square inch.

January to July, 1919, the pressure fell 35 pounds, and fr July, 1919, to January, 1920, the decrease was over 150 poun (See figure 5.) During the last few weeks of 1919 the pr sure declined about one pound daily. If the decrease in pr sure continues at the present rate, the field will probably sh signs of exhaustion during the fall of 1920, and it is possi that the compressor station will be needed next winter. It m be that the pressure will decline to a certain point and th tend to decrease less rapidly, many fields acting in this mann As a rule, however, the gas fields of high initial pressure a volume are of rather short duration, as compared to those medium pressure and smaller initial volume.

Offset wells drilled during the fall of 1919 came in with pr sures sufficient to throw the tools over the top of the rig.

ginal pressure in some of these new wells was as high as 0 pounds, which would indicate that the sand at these points s as yet relatively unaffected by lines of drainage from the ler wells. However, the pressure in these new wells tends to crease rather rapidly, and in a few months is about the same the older wells. Although the sand is fairly compact, it apars, therefore, that interfering drainage lines tend to equal- the pressure between the newer and older wells.

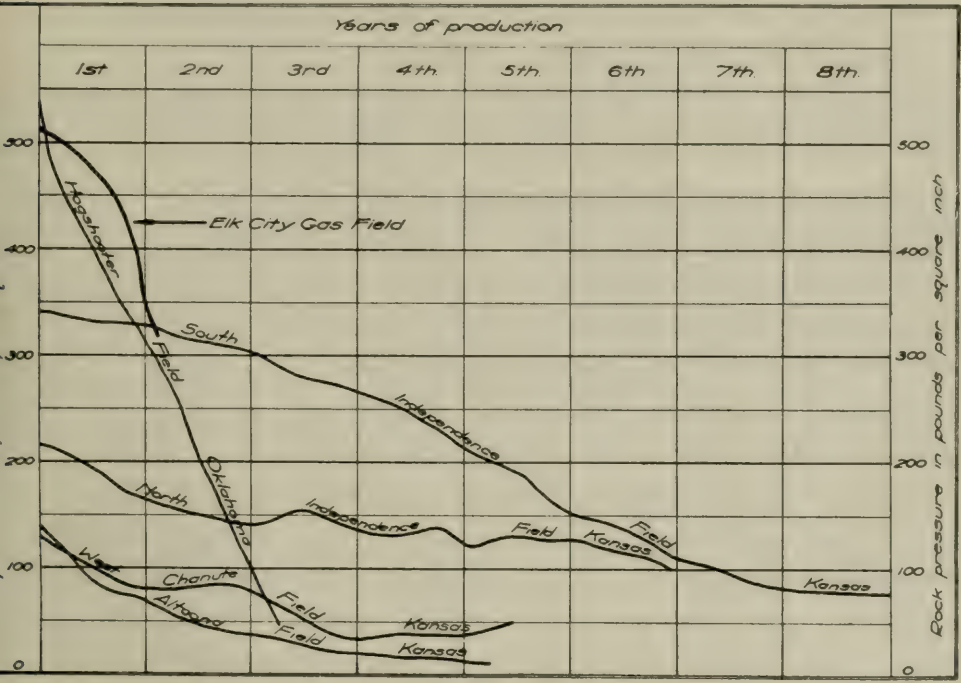


FIGURE 6.

gram showing the comparative decline in rock pressure in important southeast Kansas and Oklahoma gas fields. (From Johnson and Hunt- ey, Principles of Oil and Gas Production.)

METHOD OF DETERMINING PROBABLE FUTURE PRODUCTION.

Little has been done in working out a satisfactory method determining the future production of gas fields. Johnson 1 Huntley* have evolved a formula which in some cases may rk out very well, yet it is admitted that the life of a field is dified by the rate at which the pressure declines, by the mber of wells drilled in the pool, by the encroachment of salt ter, by retardation in tight sand wells, by the size of the res- oir, and sometimes by leakage through the well into an upper low-pressure sand. It is obviously a difficult matter to determine all of these factors. The method proposed by Johnso and Huntley takes into consideration the original pressure, th amount of the decline, the pressure at which the field will ceas to be of great value, the total amount of gas produced, and th daily output. Assuming that the Elk City field has produce seven and a half billion cubic feet, the formula and result woul be as follows:

---

* Johnson and Huntley, "Principles of Oil and Gas Production," 1916, page 164.

$$\frac{\text{Original pressure minus 40 (minimum working pressure).}}{\text{Decline in pressure.}} \times \text{Amount of gas produced.}$$

Substituting: $\frac{520-40}{200} \times 7.5$ billion = 18,000,000 cubic fee

which is theoretically, according to this calculation, the amou of gas remaining in the pool. If the present rate of productio could be maintained, the field should last approximately 45 days, according to this formula. However, the yield of a ga field declines with the pressure, so that although the Elk Cit pool may yet contain 18 billion cubic feet of gas, it is hard probable that this amount will be marketed within the ne 450 days. It is probable that the pressure will decline to suc an amount as to make it necessary to use the compressor st tion next winter, yet it is believed that the Elk City field will producing gas two or three years hence. A list of five g fields in southeastern Kansas, with comparative figures as depth, thickness of the gas sand, initial pressure and volum life, and extent of the producing area, is given in "Appendix C

Figure 6 shows the pressure decline and life of six gas fiel in southeastern Kansas and northeastern Oklahoma. It is be noted that thus far the curve for the Elk City field close resembles that for the Hogshooter field of Oklahoma, whi produced enormous quantities of gas for about two years.

FUTURE DEVELOPMENT.

As previously stated, fifty-three producing wells have be drilled in the Elk City field. There is space for possibly t good additional well locations, which will be drilled from ti to time as the yield declines, so as to maintain the output as nearly a constant level as possible. The average dista between the wells should not be less that 1,000 feet, althou in some parts of the field they are more closely spaced beca

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f property lines and the consequent necessity for offsets. In-
eed, there is at present a sufficient number of wells to drain
he entire pool, but they are not so arranged as to make this
s thorough as possible. The life of the individual wells and
f the entire field would be lengthened if production could
e restricted to a small number of wells. The extent of the pro-
ucing area has been determined on the east, south, and west,
nd it is expected that future development will extend toward
e northwest, although one or two dry holes have already been
ncountered in this direction.

It is possible that the ridge of Mississippian limestone, which
as been described, extends some distance to the northwest, and
ere is a possibility that favorable sand conditions may be
epeated elsewhere along its course.

Recent developments in northeastern Oklahoma demonstrate
at excellent production may be secured below the top of the
ississippian limestone. Subsurface conditions in the Elk
ity field show that there is a possibility of favorable structure
the Mississippian strata. Any deep test should extend at
ast 400 feet into the limestone.

---

ata on Wells in the Region of the Elk City Gas Field.

APPENDIX A.

Farm.	No.	Depth to gas sand.	Depth to Miss. Ls.	Production (initial).
ugustine	1	......	1450 ft.	Dry.
allinger	1	......	......	9,000,000 cu. ft.
allinger	2	......	1450 ft.	Dry.
aum	1	1340 ft.	......	23,500,000 cu. ft.
aum	2	1345 ft.	......	25,850,000 cu. ft.
aum	3	1354 ft.	......	24,600,000 cu. ft.
aum	4	1336 ft.	......	33,750,000 cu. ft.
aum	5	1343 ft.	......	27,000,000 cu. ft.
aum	6	1375 ft.	......	33,000,000 cu. ft.
aum	7	......	......	33,000,000 cu. ft.
rainerd	1	1355 ft.	......	22,000,000 (water)
rainerd	2	1367 ft.	......	20,000,000 (dead)
rainerd	3	......	......	24,600,000 cu. ft.
rainerd	4	......	......	33,700,000 cu. ft.
rainerd	5	......	......	30,000,000 cu. ft.
rooke	1	......	......	14,800,000 (dead)
ryant	1	1370 ft.	......	Dry.
halfant	1	......	......	27,000,000 cu. ft.
halfant	2	1352 ft.	......	33,750,000 cu. ft.

Farm.	No.	Depth to gas sand.	Depth to Miss. Ls.	Production (initial).
Cox	1	1358 ft.	......	Drowned; oil and water.
Denton	1	1357 ft.	......	Show of gas.
Gray	1	1346 ft.	......	26,600,000 cu. ft.
Gray	2	1338 ft.	......	33,100,000 cu. ft.
Gray	3	......	......	11,000,000 cu. ft.
Hancock	1	......	......	33,000,000 cu. ft.
Hancock	2	1332 ft.	......	55,000,000 cu. ft.
Hemper	1	1307 ft.	......	20,000,000 cu. ft.
Hemper	2	1340 ft.	......	23,000,000 cu. ft.
Hett	1	1335 ft.	......	22,000,000 cu. ft.
Hett	2	1315 ft.	......	18,000,000 cu. ft.
Hett	3	1321 ft.	......	52,980,000 cu. ft.
King	1	1331 ft.	......	20,000,000 cu. ft.
King	2	1353 ft.	......	22,000,000 cu. ft.
King	3	1371 ft.	......	32,000,000 cu. ft.
King	4	1327 ft.	......	86,700,000 cu. ft.
King	5	......	......	22,500,000 cu. ft.
Lewis (sec. 23)	1	1468 ft.	1495 ft.	1,500,000 cu. ft.
Lewis	2	1440 ft.	......	22,000,000 cu. ft.
Lewis	3	......	1432 (?)	Dry.
Lewis (sec. 26)	1	1358 ft.	......	31,700,000 cu. ft.
Lewis	2	......	......	19,600,000 cu. ft.
Lewis	3	......	......	24,000,000 cu. ft.
Lewis	4	......	......	34,000,000 cu. ft.
Lewis	5	......	......	37,000,000 cu. ft.
Masters	2	......	1507 ft.	Dry.
Simmons	1	1340 ft.	......	10,000,000 (water and oi
Simmons	2	......	......	32,000,000 (water)
Simmons	3	1337 ft.	......	22,570,000 (water)
Simmons	4	......	......	27,200,000 cu. ft.
Stephens	1	1360 ft.	......	Dry.
Stephens	2	......	1452 ft.	Dry.
Spaht	1	......	1515 ft.	Dry.
Spaht	2	......	1580 ft.	Dry.
Spaht	3	......	1387 ft.	Dry.
Starks	1	......	1623 ft.	Dry.
Welchel (N. E. ¼ sec. 26)	1	1350 ft.	......	24,500,000 cu. ft.
Welchel	2	......	......	38,000,000 cu. ft.
Welchel	3	......	......	14,500,000 cu. ft.
Welchel (S. W. ¼ sec. 26)	1	1330 ft.	......	36,000,000 cu. ft.
Welchel	2	1330 ft.	......	32,000,000 cu. ft.
West	1	1327 ft.	......	19,500,000 cu. ft.
West	2	......	......	41,600,000 cu. ft.
West	3	......	......	33,500,000 cu. ft.
West	4	......	......	35,700,000 cu. ft.
West	5	......	......	60,000,000 cu. ft.

APPENDIX B.

Data showing the amount of gas marketed by the Southwestern Gas Company from the Elk City field:

December, 1918	126,267,000 cu. ft.
January, 1919	372,431,000 cu. ft.
February	564,067,000 cu. ft.
March	672,721,000 cu. ft.
April	567,968,000 cu. ft.
May	230,889,000 cu. ft.
June	319,043,000 cu. ft.
July	261,626,000 cu. ft.
August	226,000,000 cu. ft.
September	353,290,000 cu. ft.
October	839,478,000 cu. ft.
November	798,408,000 cu. ft.
December	808,713,000 cu. ft.
	6,140,901,000 cu. ft.
Amount of gas marketed by Nicholson Pipe Line Company, estimated at 8,000,000 cubic feet daily for 180 days	1,440,000,000 cu. ft.
Total amount of gas marketed, probably about	7,580,901,000 cu. ft.

APPENDIX C.

The following is a list of five gas fields in this part of the tate, giving comparative figures as to depth, thickness of the roducing sand, initial pressure and volume, life, and extent of he producing area:*

Havana.—Depth, 800 feet; sand thickness, 15 to 50 feet; initial pres-
ure, 265 pounds; initial volume, average, 3 million; life, 5 years; area, 0 to 15 square miles.

Sedan.—Depth, 700 feet; sand thickness, 10 to 40 feet; initial pressure, 85 pounds; initial volume, average, 5 million; life, 10 years; area, 8 to 0 square miles.

Hale.—Depth, 800 feet; sand thickness, 50 to 60 feet; initial pressure, 55 pounds; initial volume, average, ½ to 3 million; life, wells hold good; rea, 8 to 10 square miles.

New Albany.—Depth, 1,200 feet; sand thickness, 22 feet; initial pres-
ure, 320 pounds; initial volume, average, 3 to 12 million; life, 18 months.

Elk City.—Depth, 1,350 feet; sand thickness, 20 to 30 feet; initial pres-
ure, 520 pounds; initial volume, average, 1½ to 86 million; area, 3½ quare miles.

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* Supplied in part by Mr. E. M. Stryker, of Fredonia, Kan.

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STATE GEOLOGICAL SURVEY *of* KANSAS
RAYMOND C. MOORE, State Geologist

OIL *and* GAS RESOURCES *of* KANSAS

PART I

GENERAL GEOLOGY *of* OIL *and* GAS

By RAYMOND C. MOORE

BULLETIN 6

Printed by authority of the State of Kansas.

PRINTED BY THE STATE PRINTING PLANT
IMRI ZUMWALT, STATE PRINTER
TOPEKA, KANSAS

Publications of the State Geological Survey are distributed from
Lawrence, Kansas.

8-4047

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STATE GEOLOGICAL SURVEY OF KANSAS.

ERNEST H. LINDLEY, PH. D.,
Chancellor of the University of Kansas and *ex officio*
Director of the Survey.

RAYMOND C. MOORE, PH. D.,
State Geologist.

LETTER OF TRANSMITTAL.

r. E. H. Lindley, Chancellor of the University of Kansas,
ex officio Director of the State Geological Survey:

SIR—The oil and gas resources of this state constitute one f its most important natural assets, the development of which n recent years has advanced remarkably. The amount of these uels already produced places Kansas very high on the list of il- and gas-producing states. In view of the rapidly increasng demand for oil and gas and the declining production from nown fields, it is very important that undeveloped resources e found. Much of the state of Kansas is prospective or posible oil and gas territory, and the demand for authentic inormation concerning the oil and gas industry in Kansas, the ossibilities of future development and the application of geoogical knowledge to the problems of increased production is onstantly increasing.

It is proposed to issue the present report in parts, in order oth to expedite the publication and to make readily available o citizens of the state information covering different phases f the subject and different portions of the state. The report ill constitute Bulletin 6 of the Reports of the State Geological urvey of Kansas.

Respectfully submitted.

RAYMOND C. MOORE,
State Geologist.

CONTENTS.

PAGE.

CHAPTER I.—Properties of Oil and Gas.
Introduction 7
Petroleum 7
Chemical properties 7
Physical properties 9
Natural Gas 12
Chemical properties 12
Physical properties 13

CHAPTER II.—Distribution of Oil and Gas.
Geographical distribution 14
Geological distribution 17
Containing rocks 17
Lithologic character 17
Geologic age 18

CHAPTER III.—Rocks Associated with Oil and Gas.
Kinds of rocks 20
Igneous and metamorphic rocks 20
Sedimentary rocks 2
Conglomerate 2
Sandstone 2
Shale 2
Limestone 2
Gradations 2
Formation of Sedimentary rocks 2
Deposition 2
Stratification 2
Cross-bedding 2
Place of deposition 2
Characters of sedimentary rock formations 2
General statement 2
Sedimentary rock units 2
Geologic names 2
Lithologic characters 2
Distribution and thickness 2
Fossils 2
Relation to other rocks 2
Structure 3
Dip and strike 3
Folds 3
Faults 3

HAPTER IV.—Origin and Migration of Oil and Gas.

PAGE.
- Origin of Oil and Gas 33
  - Inorganic hypotheses 33
  - Organic hypotheses 34
    - Plant origin 35
    - Animal origin 36
  - Other hypotheses 37
  - General Conclusions 39
- Migration of oil and gas 40
  - Gravitation 40
  - Capillary attraction 40
  - Displacement 41
  - Gas pressure 42
  - Difference in the specific gravities of water, oil and gas 43
- Accumulation of oil and gas 44
  - Oil and gas reservoirs 45
  - Structural relations of oil and gas 49
  - Summary 52
- Exploration for oil and gas 53
  - Direct indications 53
    - Oil seepages 53
    - Gas springs 54
    - Outcrops of sand impregnated with bitumen 55
  - Indirect indications 56

HAPTER V.—Production of Oil and Gas.

- Introduction 59
- Leasing 60
- Location of wells 62
- Drilling for oil and gas 65
  - Method of drilling 65
  - Casing 73
  - Drilling contracts 74
  - Cost of drilling 74
  - Keeping the log 74
  - Shooting the well 75
- Management of oil wells 76
  - Method of recovery 76
  - Initial production and decline of oil wells 76
  - The handling of oil 77
  - Transportation 78
  - Fire protection 79
- Refining of petroleum 79
  - Refining methods 79
    - "Dry" or "cracking" distillation process 80
    - Fractional distillation 81
    - Vacuum process 81
  - Pressure distillation 81
  - Petroleum products manufactured in the Midcontinent field 81
- Percentage of gasoline content 82
- Condensation of gasoline from natural gas 83

ILLUSTRATIONS.

PLATE.
I. Specific gravities of American petroleums.
II. Map showing the distribution of the oil fields of the world.
III. Map showing the distribution of oil fields in the United States.
IV. Pore space of rocks.
V. Stereogram showing surface topography and underground structure of a typical oil and gas pool.
VI. Standard drilling outfit, coupled for raising tools.
VII. Drilling tools.
VIII. Star drilling rig.

FIGURE.
1. Diagram showing the distribution of oil produced in the United State by geologic periods.
2. Diagram showing oil and gas in porous lenses.
3. Diagram showing oil in a syncline.
4. Diagram showing oil sealed in by a fault.
5. Topographic map of a small area showing the position and elevatio of outcrops of a prominent limestone bed.
6. Structure contour map of area shown in figure 5, indicating the elevation and structure of prominent limestone bed.
7. Vertical cross section along line A-B across area shown in figure
8. *A*. String of tools used with standard drilling outfit. *B*. Tempe screw.
9. Percentage content of Midcontinent crude petroleum.

CHAPTER I.

PROPERTIES OF OIL AND GAS.

INTRODUCTION.

ETROLEUM[1] and natural gas[2] are naturally occurring materials of the greatest economic importance which are idely, though not uniformly, distributed in the rocks of the arth. In some cases they are found under enormous pressures nd in almost incredible quantities, but in general their occurence is limited. At the present time so very great is man's se of petroleum and natural gas that they have become almost ndispensable to him.

PETROLEUM.

CHEMICAL PROPERTIES.

Composition. Even prior to the discovery of commercial uantities of petroleum, a number of determinations of its hemical composition were made. These analyses, supplenented by much recent investigation, show that petroleum onsists of about 84 to 87 per cent carbon and 11 to 13 per cent ydrogen, with varying small proportions of sulphur, nitroen and oxygen.

Ultimate Analyses of Petroleum.[3]

Locality.	Specific gravity.		Carbon.	Hydrogen.	Oxygen. Nitrogen.	Sulphur.
	Regular.	Baumé.				
ennsylvania	.816	39	82.0	14.8	3.2	Trace
Vest Virginia	.841	36	84.3	14.1	1.6	Trace
Vest Virginia . ..	.873	30	83.5	13.3	3.2	Trace
ennsylvania	.886	28	84.9	13.7	1.4	Trace
hio	.887	28	84.2	13.1	2.7	Trace
exas	.921	22	84.6	10.9	2.9	1.63
alifornia	.965	15	81.5	10.0	6.9	.55

Hydrocarbons. The various hydrocarbons[4] of which petroleum is chiefly composed, fall primarily into a regular series, in which a number (n) of hydrogen (H) atoms are combined with a given number (n) of carbon (C) atoms in the ratio indicated by the following series of generalized formulæ:

---

[1] Petroleum (Latin, *petra*, rock, and *oleum*, oil) in its widest sense embraces all of he hydrocarbons, gaseous, liquid, and solid, occurring in nature. The term is, in practice, limited to the liquid forms, and synonymous with the simple word "oil" so widely sed by geologists and the industry in general.

[2] Natural gas, as the term is applied, has come to have technical meaning, referring nly to those gases occurring in rocks which are sufficiently inflammable to be used as a uel or illuminant. Volcanic gases, or gases of the atmosphere, are also "natural," but re not included in the common use of the term.

[3] A chemical analysis showing the irreducible elements of which it is composed is nown as an *ultimate analysis*.

[4] The analysis of petroleum which consists in the separation of its various components, and in their identification as hydrocarbons of definite constitution, is known as a roximate analysis. The exact nature of these various hydrocarbon compounds, of which here are a very large number, is in most cases not easily determinable.

C_nH_{2n+2}	Paraffin series.
C_nH_{2n}	Olefine and naphthene series.
C_nH_{2n-2}	Acetylene series.
C_nH_{2n-4}	
C_nH_{2n-6}	Benzene series.
C_nH_{2n-8}	
C_nH_{2n-10}	
C_nH_{2n-12}	

The series represented in these formulæ have all been recognized in petroleum. Each includes many members, the paraffin series, for example, beginning with marsh gas or methane, CH_4, ranges at least as high as the compound $C_{35}H_{72}$. The lower members in this instance are gaseous, the middle members are liquids, with regularly increasing boiling points, and the higher members are solids, like ordinary paraffin. Gaseous and solid hydrocarbons which are present in petroleum are in solution. The paraffins[5] are found in all crude oils, in many cases composing the largest proportion of the oil. The olefine series occurs in the majority of petroleums and is important in a few. The acetylene series is represented in some petroleum, notably that from the Baku district of Russia. Members of the benzene series, especially benzene and toluene, occur in all petroleums, but not in large amounts. Certain crude oils have been found to contain camphenes, napthalenes and other so-called aromatic hydrocarbons.

Impurities. Sulphur may be present in crude petroleum either as free sulphur, as a constituent of hydrogen sulphide or as an organic sulphur compound. Petroleum entirely free from sulphur is extremely rare, but the amount of this constituent is commonly very small. Most petroleum contains some nitrogen, but it rarely exceeds 2 per cent. In most cases it exists in the form of complex organic compounds. Small amounts of oxidized materials, as complex acids and phenols are found in some oils.

---

[5] Petroleum which contains chiefly the paraffin hydrocarbon series and which yield paraffin when the heavier distillates are subjected to a freezing temperature, is said t have a *paraffin base*. Crude oils which upon evaporation yield a residue consisting essentially of asphalt, are said to have an *asphaltic base*. Some oils, including representativ Midcontinent samples, have both paraffin and asphaltic bases.

PHYSICAL PROPERTIES.

Color. Most crude oils are opaque by transmitted light except in very thin layers. Many of the lighter grades, however, notably certain oils from Pennsylvania, Wyoming and Alberta, range in color from a pale straw yellow, through red and brown, to dark green. By reflected light most crude oils have a greenish cast.

Refractive Index. Of scientific interest and technical importance is the effect exerted by petroleum on light rays which are passed through it. Thus, the refractive index has significance regarding the origin of various petroleums, and may be used in their identification. It is observed, also, that certain crude oils and their distillates rotate slightly the plane of polarized light, the direction of rotation being in general to the right.

Odor. The odor of certain crude oils is very characteristic. The oils from Pennsylvania and parts of the Midcontinent region have the odor of gasoline. Much of the Texas and Mexican oil has the disagreeable odor of hydrogen sulphide.

Specific gravity. One of the important physical properties of petroleum, affording the basis of a rough classification which may be correlated with the proportion of more valuable light oils contained, is specific gravity. Crude oils show an extreme range in specific gravity from .771 to 1.060, the average being between .800 and .980.

The specific gravity of any substance is the relation it bears by weight to the same volume of water. Water has a specific gravity of 1. Most petroleums are lighter than water, and hence have a specific gravity less than 1, the amount being commonly expressed in decimals, as .850, for average Kansas oil. For the measurement of the specific gravity of fluids, such as oil, a thermometer and an hydrometer are used. The hydrometer is a glass tube, enlarged and weighted at the lower end, so that when placed in a fluid it will float upright, being submerged to an amount depending on the relative weight or buoyancy of the fluid. The upper part of the tube is marked with graduations from which may be determined the amount of submergence, and from this the relative weight or specific gravity of the fluid. The scale commonly used is that devised by a French chemist, Antoine Baumé, in 1768, and after him known as the *Baumé scale.* A specific gravity of 1, compared with water, is arbitrarily chosen as 10° on the Baumé scale. Ordinary specific gravity determinations may be converted to the Baumé scale by dividing 140 by the specific gravity and subtracting 130; Baumé degrees may be converted to specific gravity by dividing 140 by degrees Baumé and adding 130. Thus a heavy

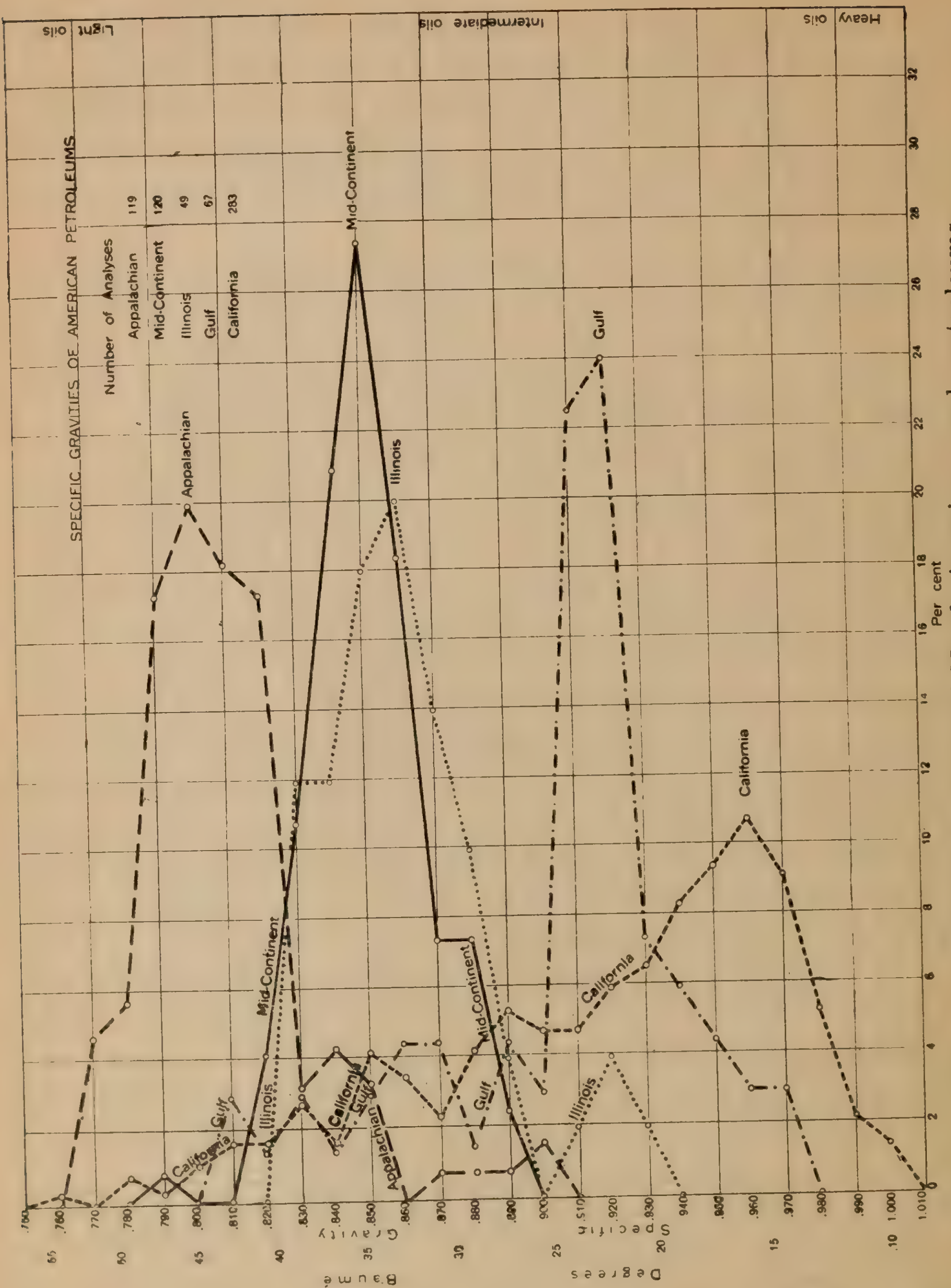

PLATE I.—Specific gravities of North American crude petroleums.

SPECIFIC GRAVITIES OF AMERICAN PETROLEUMS.—Available determinations of the specific gravity of crude oils from each field have been separately computed to 100 per cent for that field. Thus plotted they are directly comparable and show clearly the general average and the range of the crude oils of each field. About 27 per cent of the oils rereported from the Midcontinent field have a specific gravity of 0.850, or 35° Baumé. Nearly 11 per cent of California petroleums have a specific gravity of 0.960, of 16° Baumé, but the oils from this state range from 1.010 to 0.750. (Data from Mineral Resources, 1913, U. S. Geol. Survey, pp. 1126-1265.)

oil has a low gravity in Baumé degrees, and a light oil a high one. Though the Baumé scale has no marked advantage over the rational scale, the refiner and the oil trade have adhered to its use through custom.

The specific gravity of crude oils from the fields of the United States is shown in plate I. It will be observed that average Midcontinent petroleum has a specific gravity of .850, or 35° Baumé, and that more than 90 per cent of the oils tested from this field have a specific gravity between .875 and .825, or 30° and 40° Baumé. Average Pennsylvania (Appalachian) crude oils, which are relatively very light, have a specific gravity of .800 or 45° Baumé. Petroleum from Texas and Louisiana (Gulf region) have an average specific gravity of about 23° Baumé and those from California as low as 16° Baumé, though some of the California oils also are light.

Expansion. Changes of temperature produce a slight but variable change in the volume of petroleum. The coëfficient of expansion of petroleums is important for determining the expansion space to be allowed in storage vessels and for transport. Observation shows that the coëfficient of expansion decreases as the specific gravity rises. Thus a light oil has a high coëfficient of expansion and a heavy oil a low one.

Viscosity. The viscosity of petroleums, the resistance offered to flow, like the specific gravity, shows a considerable range. Indeed, a somewhat direct relation appears to exist between these properties, certain of the very light paraffin oils being remarkably fluid and the heavier asphaltic oils showing an increase of viscosity with specific gravity. Temperature, however, has an important effect on the viscosity of petroleum. The viscosity of crude oil is an important character because it determines the facility with which it may be pumped through pipe lines. Some oils flow with such reluctance that they must be heated before they can be pumped. The heavy oils with high viscosity can be transported by pipe line only in the warm summer months. Crude petroleum solidifies when cooled to a temperature varying from 82° F. in the case of some Burma oils, to several degrees below zero in certain very light Italian oils.

Flashing point. The flashing point, or the lowest temperature at which inflammable vapors are given off, is a matter of concern in the case of certain oils. It has an extreme variation, from below zero in the Italian oils to more than 300° F. in certain oils from Africa.

Boiling point. The boiling points of petroleums and the distillates obtained at specified temperatures differ very considerably, also, in the crude oils obtained from different sources. Distillation begins at lower temperatures in the lighter oils and at higher temperatures in the heavier oils.

Heating value. The heating or calorific value of crude petroleum is an important character, especially in view of the rapid increase in the use of crude oil and residues for fuel in steam plants, and railway and marine engines. Some of the very heavy crude oils are used almost entirely for fuel and compete to advantage with coal. Many of the lighter, high-grade petroleums, after partial distillation, also, furnish a residue which is sold as fuel. The average heating value of crude petroleum from the mid-continent field is about 10,900 calories[6] or 19,600 B. T. U. Good average coal has a heating value of about 7,500 calories, or 13,500 B. T. U.

NATURAL GAS.

CHEMICAL PROPERTIES.

Composition. Natural gas contains only the lightest and most volatile of the hydrocarbons. It consists chiefly of the lower members of the paraffin series, especially marsh gas, or methane, which has the chemical formula CH_4. Ethane (C_2H_6) is present in considerable quantities in the natural gas from some regions. In association with these hydrocarbons there may be varying quantities of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulphide (H_2S), hydrogen, oxygen and nitrogen. Some of the natural gas from Kansas is of more than usual interest because of its remarkably high nitrogen content, a sample from Dexter, Cowley county, containing 82.7 per cent of this element. Helium, to more than 2 per cent, argon, and the rare element neon, have been discovered in the natural gas of Kansas.

Analyses of Average Gas from Various Kansas Fields.

Locality.	Carbon dioxide. CO_2	Oxygen. O_2	Methane. CH_4	Ethane. C_2H_6	Residue.
Allen county	2.22	.34	90.62	3.67	3.25
Arkansas City	.07	.24	65.63	15.30	18.76
Augusta	.23	.34	68.75	15.46	15.22
Montgomery	.90	.22	85.91	9.12	3.85
Winfield	.12	.61	71.77	10.75	16.75

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[6] A calory is the heat required to raise the temperature of 1 gram of water 1° Centigrade. The British thermal unit (B. T. U.) is the pound-degree, or the amount of heat required to raise a pound of water 1° Fahrenheit.

There are two general types of natural gas: (1) "dry" gas, which consists principally of methane (CH_4) with a small content of ethane (C_2H_6) and nitrogen, and (2) "wet" or casing-head gas, which contains beside methane varying amounts of the heavier hydrocarbons. The dry gas is the chief type produced in most localities. It does not contain any appreciable amount of readily condensible gasoline and is not usually closely associated with petroleum. Wet or casing-head gas contains condensible gasoline. It is characteristically associated with petroleum and is yielded with the oil in many wells. It also comes from the gas wells in oil pools, producing from the oil-containing strata.

PHYSICAL PROPERTIES.

Although natural gas is somewhat closely related chemically to petroleum, its physical properties are very different. Of first importance, of course, is the gaseous character of its constituent hydrocarbons, which necessitates methods of handling commercially quite different from those used in oil production. The gas is colorless, practically odorless, and burns with a luminous flame. When mixed with air it is highly explosive.

In heating value, natural gas varies considerably, depending on the chemical character and proportion of its combustible hydrocarbons and the relative quantities which are present of such incombustible impurities as nitrogen. The heating value of natural gas is high, as shown by numerous tests. Dry gas has a value amounting to about 525 calories or 950 B. T. U. per cubic foot. Thus about 135 cubic feet of natural gas is equivalent in heating value to one gallon of average mid-continent fuel oil. Casing-head gas may have a heating value as high as 2,500 B. T. U. and rarely falls lower than 1,000 B. T. U. Natural gas has a much higher heating value than manufactured gases. In many respects it may be regarded as an ideal fuel because of its cleanness, ease of handling, efficiency of combustion, and low content of poisonous constituents.

CHAPTER II.

DISTRIBUTION OF OIL AND GAS.

PETROLEUM is found in many parts of the world and under a variety of geological conditions. Observations concerning its distribution guide the search for new deposits and assist in the efficient development of known fields. A summary of these observations may be presented here as an introduction to the more detailed consideration of the occurrence of oil in the succeeding chapters.

GEOGRAPHICAL DISTRIBUTION.

There is hardly a country in the world in which petroleum, in large or small quantity, has not been found. It is known both in high latitudes and in the tropics, in the eastern hemisphere and in the western, on islands and on the continents. Oil has been found in lofty plateaus and mountain ranges; it is also known very deeply below the level of the sea. There appears to be no simple limiting factor of a geographic nature in the distribution of petroleum.

The occurrence of oil is by no means uniform, however. In some places it is concentrated in enormous quantities and under very great pressures. In other places the quantity of oil is so small, or it is so disseminated and so difficult to extract that at least under present conditions, the deposit cannot be regarded as of commercial importance.

Oil fields and districts. In any given oil-containing region, as for example the Mississippi valley in the United States, it may be observed that the commercially valuable accumulations are restricted to certain relatively small parts of the general region. These are conveniently known as oil "fields." The Midcontinent field, comprising parts of Kansas, Oklahoma and northern Texas, and the Lima-Indiana field, which includes portions of eastern Indiana and western Ohio, are examples. Much the greatest portion of the Mississippi valley region is not included in any of the oil fields.

Detailed maps of any of the so-called oil fields shows that the oil comes chiefly from rather small areas, which are separated by unproductive territory. These more or less isolated areas of large production are commonly known as "pools" or districts. The El Dorado district, in Kansas, and the Cushing

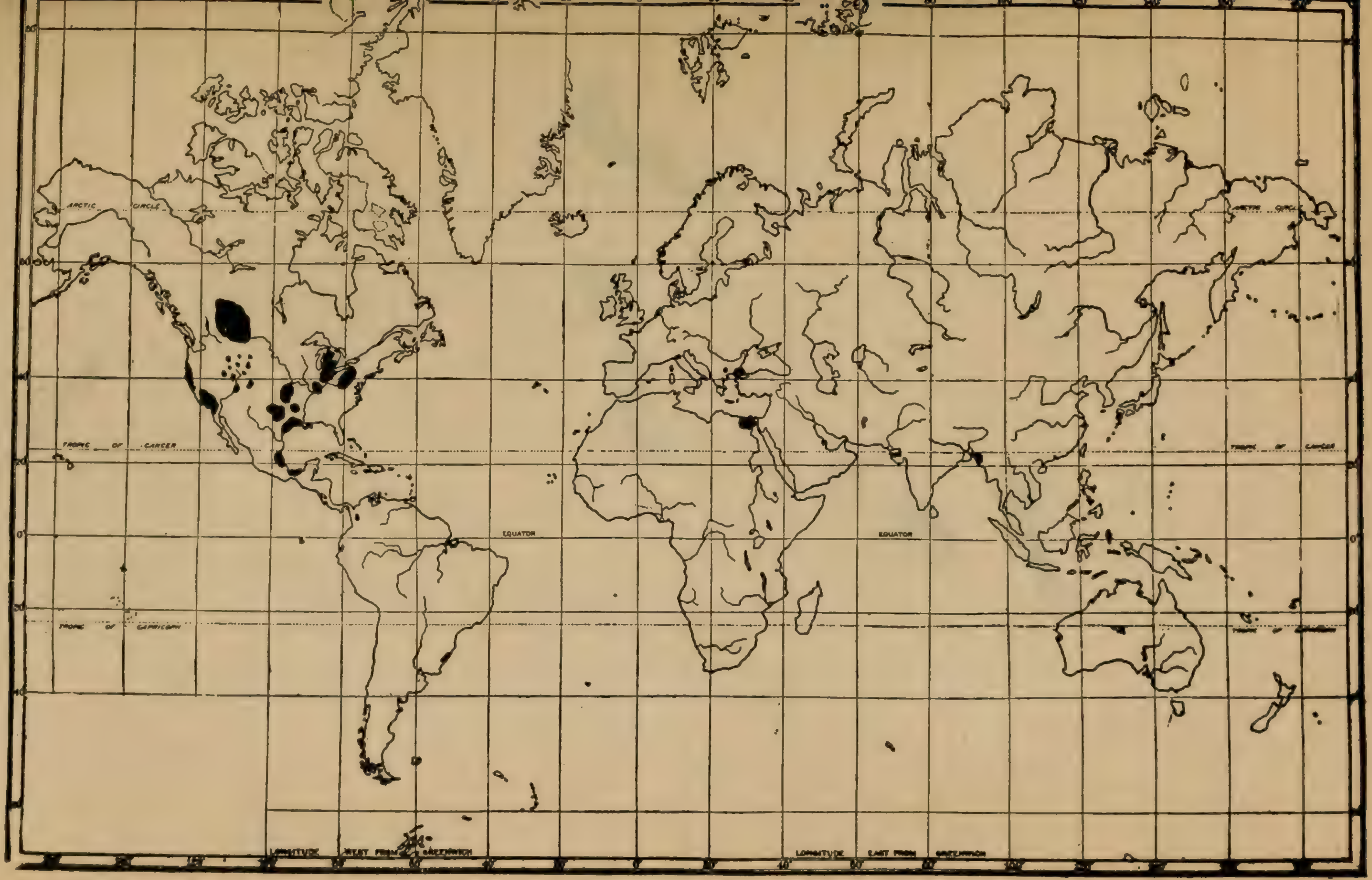

PLATE II.—Map showing distribution of oil in world.

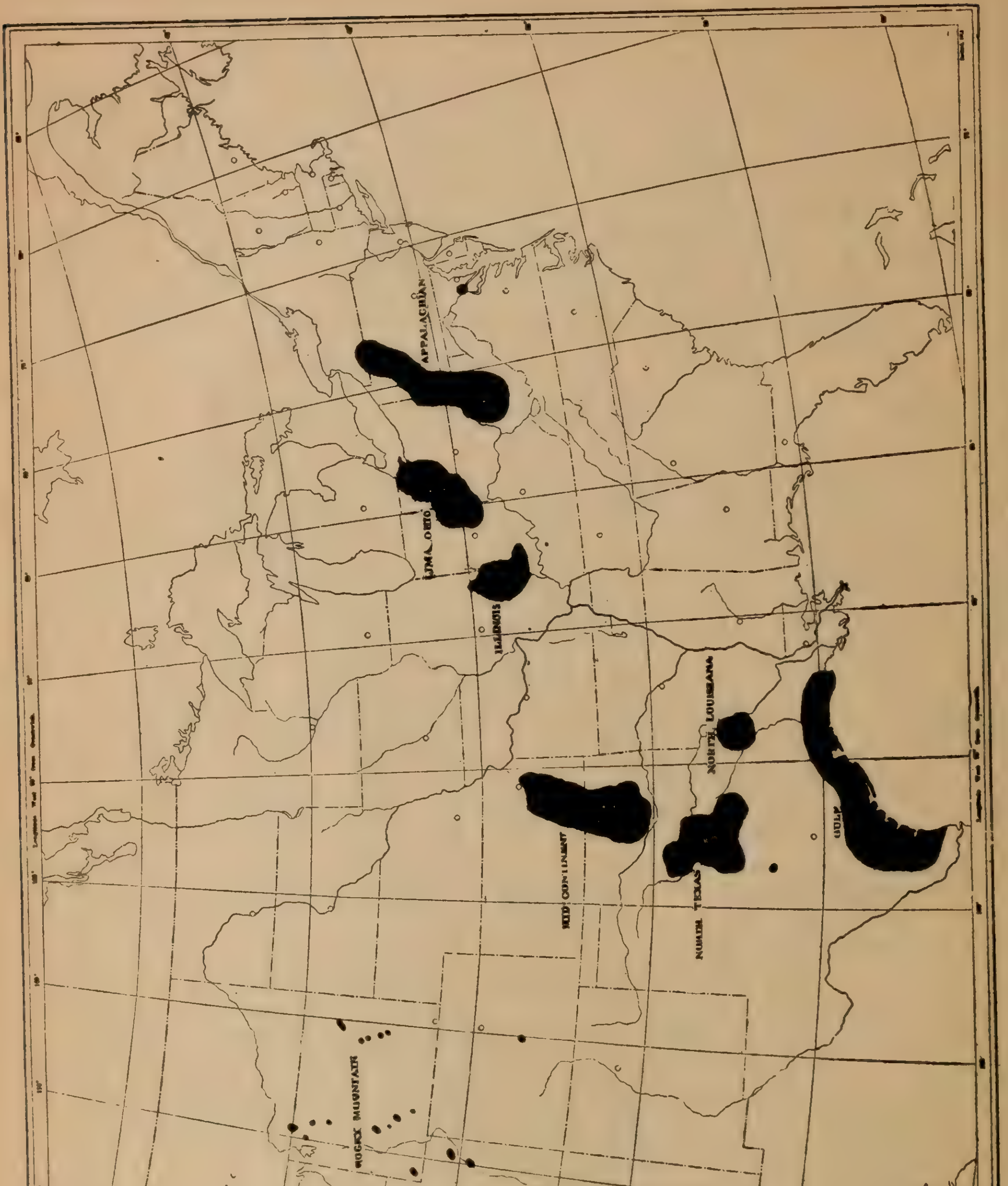

PLATE III. Map of United States, showing "oil fields."

district, in Oklahoma, are such very productive areas or pools in the Midcontinent field. They are separated from other parts of the field by unproductive territory. (See Map Kansas Oil Field, Part III.)

Finally, it is to be observed that within a given oil-producing district or pool there may be spots where there is no commercial production. This is especially true in some of the Midcontinent oil districts.

GEOLOGICAL DISTRIBUTION.

Depth. Oil comes naturally to the surface in some localities n springs and seepages. Beneath the surface of the earth it s found in some places at very shallow depths, but in others at depths of as much as one mile. The oil obtained in the discovery well drilled by Drake in 1859 was found at a depth of 69 feet. A well recently drilled in West Virginia, not far distant from the first American oil well, reached a depth of 7,579 feet[7] but did not succeed in attaining the oil- and gas-bearng horizon which it was intended to test. Probably the lower imit of important quantities of oil is not more than one mile; for at great depths the pore space in the rocks is reduced by compacting due to the weight of overlying rocks. The greatest deposits of commercially available oil are found at intermediate depths, that is, more than 1,000 feet and less than 3,000 or 3,500 feet. In the zone near the surface there is maximum possibility of the dissipation of oil accumulations through fracturing and erosion. In some districts, or even in individual wells, oil is obtained from several horizons which may be separated by several hundred feet of unproductive strata. Apparently depth is not a controlling factor in the formation of an oil deposit of commercial value, though it is a very important factor in the cost of development. Oil may be encountered at almost any depth down to one mile or perhaps more.

CONTAINING ROCKS.

Lithologic character. In small quantities, oil has been found n almost all kinds of rocks. In some, however, the occurrence s very evidently the result of special geologic conditions and s not of commercial importance. Valuable accumulations of oil are confined to sedimentary rocks. This is due to the facts that the oil apparently originates in the sedimentary rocks and that in certain of them is found the requisite porosity. Sand and sandstone, which are commonly the most porous sedimentary rocks, are the most important containers of commercially available oil deposits. So general, indeed, is the association of oil production with sands or sandstone that in practice almost any rock from which oil is obtained in a well is known as a "sand." In some fields considerable amounts of oil have been obtained from porous, fractured or water-channeled limestone[8] and from fissured shale.[9]

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[7] Lake well No. 1, Hope Natural Gas Company.

Geologic age. The known oil deposits are not confined to the rocks of any particular geologic age. About 57 per cent of the world's total production, however, comes from Tertiary strata,

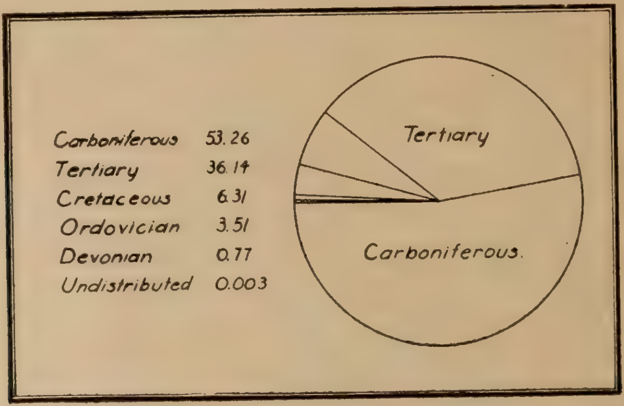

FIGURE 1.—Diagram showing the distribution of oil produced in the United States by geologic periods.

and more than 25 per cent from the Carboniferous. The remainder comes chiefly from the Cretaceous, Devonian and Ordovician. The chief Tertiary fields in North America are those in California, Texas, Louisiana and Mexico. All of the important foreign oil fields, those of Russia, Roumania, Galicia Dutch East Indies, Peru and Trinidad, produce from Tertiary formations. The commercial production of petroleum from Paleozoic rocks is confined to the North American continent In the Midcontinent field the oil is obtained from the Pennsylvanian, in the Appalachian field from Devonian and Mississippian beds and in the Lima-Indiana field from the Ordovician Production in Illinois is obtained from the Mississippian. In New York and Ontario oil has been obtained from the Devonian and Silurian. The chief Cretaceous fields are those in Wyoming, Colorado, Gulf coast region and Mexico.

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[8] Lima-Indiana field, and Mexican fields.

[9] Florence and Boulder fields, Colorado; Gaines pool, Pennsylvania.

The absence of important production from Permian, Triassic nd Jurassic rocks is doubtless due to lack of original organic naterial in the case of these formations in North America, ut in other parts of the world where they are at least in part bundantly filled with organic matter it is possibly due to lack f exploration and development.

Structure. Study of the geologic conditions associated with arge accumulations of petroleum in the known oil fields of he world indicates that there is an important relation between he occurrence of the oil and the position or structure of the ocks which contain them. The oil is found, in most cases, in he upper part of the porous containing rock; if gas is present, lso, immediately beneath the gas. Salt water, which is comnonly associated with the oil, occurs beneath the oil.

The position of the oil accumulation appears to depend prinarily on the shape and position of the containing porous rock r reservoir. In some cases, especially if the reservoir is lenticlar in shape, commercially important deposits are found in trata which are essentially horizontal or inclined in one direcion. Most commonly, however, large amounts of oil are found vhere the containing rock has been arched in such a manner hat one portion is higher than other parts. These structures, nticlines, domes and terraces, which are most favorable for mportant accumulations of oil, it is largely the work of the eologist to determine.

CHAPTER III.

ROCKS ASSOCIATED WITH OIL AND GAS.

KINDS OF ROCKS.

THERE are many kinds of rocks, but only a few are likely to contain important quantities of oil or gas or to be associated with such deposits. One who seeks in a scientific manner to find and develop the natural accumulations of oil and gas which occur in the earth must understand the essential characters of the rocks which are associated with them.

Based on their mode of origin, three main classes of rocks are commonly recognized by geologists. These are, (1) igneous rocks, which have been formed by the cooling and solidification of a lava or magma, (2) sedimentary rocks, which have been formed, chiefly under water, of particles derived by mechanical or chemical agents from previously existing rocks and (3) metamorphic rocks, which have been formed from igneous or sedimentary rocks by alteration (due chiefly to heat and pressure) which has partly or wholly obscured their original characters.

IGNEOUS AND METAMORPHIC ROCKS.

Igneous and metamorphic rocks which are frequently classed together as crystalline rocks, are, in general, quite compact and rather hard. In practically no cases have they been found to contain important deposits of oil or gas. This is due both to their low porosity and to the unfavorable conditions for the formation of oil or gas in such rocks.

Igneous rocks include (1) solidified lavas of all sorts which have been poured out on the earth's surface from volcanoes o other vents, and (2) magmas which have cooled and hardened below the surface. The former comprise the extrusive rock such as basalt, rhyolite, volcanic tuff, ash and scoria.

No typical surface igneous rocks are known in Kansas, but beds o volcanic ash are known in Phillips, Norton, Meade and Harper counties Lava-capped mesas occur a short distance outside the state in southeastern Colorado.

The latter include dike and vein rocks which are in general characterized by a porphyritic texture, and the deep-seated coarse-grained rocks which crystallized deep below the surfac f the earth. The last mentioned, represented by such well-nown rocks as granite, are exposed at the surface only after ong erosion.

A single very small outcrop of igneous rock, a dark-colored basic rock, as recently been found in Riley county,[10] but elsewhere in Kansas the gneous rocks do not appear at the surface. Crystalline rocks, chiefly ranite, underlie all of Kansas and in the central part of the state rise to vithin a relatively short distance of the surface, a fact which has had a ery important bearing on the search for oil and gas and probably also n the formation of the important commercial accumulations of this egion.

Metamorphic rocks are in some cases developed locally as rom the heating and chemical alteration produced by ascending lava or heated waters, or they may be formed over a considerable region by great pressure and heat which affect a large rea. Metamorphic rocks of the first class have been observed outh of Yates Center, Woodson county, at the very old mining amp called Silver City, now abandoned. Since the heat and ressures which are associated with the making of metamorphic rocks are so great that any oil or gas which may originally have been present has been driven off, these substances re never found in association with metamorphic rocks except n unimportant cases where the accumulation is certainly econdary.

SEDIMENTARY ROCKS.

The character of sedimentary rocks depends on the nature f the material from which they are formed and the degree of onsolidation or compacting which it has assumed. Four chief types of sediment, to which correspond four main types of sedimentary rocks, are commonly recognized.

Sediment.	Compacted rock.
Gravel.	Conglomerate.
Sand.	Sandstone.
Silt and clay.	Shale.
Lime deposits.	Limestone.

Conglomerate. Unconsolidated aggregates of more or less rounded or water-worn pebbles are called gravel. The gravel may be deposited by a stream or accumulated along a lake or sea beach by the action of the waves. When the pebbles are cemented together into a coherent rock, it is called conglomerate. Silica, calcite, and limonite are the principal cements that bind the particles together.

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[10] Moore, Raymond C., and Haynes, Winthrop P. Outcrop of Basic Igneous Rock in North Central Kansas, Bull. Am. Assn. Petr. Geologists, vol. 4, 1920.

There are beds of conglomerate in various parts of Kansas, but none are very thick. The most widespread are the so-called "mortar beds," which are found at or near the surface over a large part of western Kansas. The gravel was brought eastward from the Rocky Mountain region by streams which flowed across this part of the state in the Tertiary geologic period. The cementing material of these conglomerates is lime carbonate. In places the gravel grades into coarse, or even fine sand, in which cases the rock would properly be termed a sandstone. Some of the oil-producing horizons in the Peabody-Elbing field are conglomerates.

Sandstone. Sand consists of rather small, rounded or angular rock particles which are most resistant to the effects of weathering and erosion. Most sand is composed largely of grains of quartz. Sands which have been consolidated are known as sandstones. In most sandstones the grains are bound together by cementing material, but in some there is little if any cement, the grains being held together by the pressure to which they have been subjected. According to the strength and the amount of cement, sandstone is hard and firm, or soft and friable. The cementing materials in sandstones are commonly silica, iron oxide, calcite or clay. Sandstones are generally very porous rocks. In some cases the porosity is as much as 30 per cent, but where the interspaces between the grains are filled with cement or fine clay, the porosity is very much reduced. The texture of sandstones is commonly rather even. If the grains are large, the rock is coarse; if very small, fine grained, and therefore may contain large quantities of water, oil or other fluid.

There are numerous sandstone beds in Kansas, some of them 100 to 150 feet thick, or even more. In eastern Kansas the sandstones occur in association with limestones and shales which belong to the Pennsylvanian system. In many instances they contain large amounts of oil and gas. In Montgomery, Chautauqua and other counties of the southeastern part of the state, sandstones are especially common. The topography is locally very rough and broken, due to the resistance of these massive sandstone beds to weathering. The sandy soil which is formed in sandstone districts supports a thick cover of scrub oak. In the south central part of Kansas, including especially Sumner, Barber, Comanche, and Clark counties, there are extensive exposures of red sandstones which belong to the upper Permian. No oil or gas has been found in these sandstones or beneath the surface here. One of the most widespread and well-known sandstone formations in the state is the Dakota sandstone of Cretaceous age, which appears in a very irregular band extending from he north state line in Washington county southwestward to the extreme west and south parts of Kansas. This sandstone, light to very dark brown in color on account of an abundance of iron oxide cement, has a otal thickness of more than 200 feet. It extends continuously beneath western Kansas and eastern Colorado, appearing at the surface just east f the Front range of the Rocky Mountains. It is a very porous rock and carries a large volume of water from Colorado downward and eastward underground into Kansas. The water appears as springs along the outcrop of the Dakota sandstone in Kansas, and in wells which have been drilled into the rock. No oil or gas has been reported from the Dakota sandstone.

Shale. Muds and clays, which consist of exceedingly fine particles of mineral matter of various sorts, when compacted are known as shale. As in the case of sandstones and conglomerate the particles may be held together by cement, but most commonly they are packed together simply by the pressure to which they have been subjected. Consequently, shales are in general rather soft rocks, can be cut with a knife and are apt to be brittle, readily breaking into little chips. They exhibit a much more distinct stratification or bedding than sandstones or conglomerates and may commonly split very readily along the thin bedding planes. Shales have a variety of colors from light to dark. Yellow, brown, gray, drab, and black are common colors observed. Oil is found in many shale beds, but in most cases not in sufficient quantities to be of commercial value. Some of the oil-bearing shales from Colorado and adjacent areas to the northwest are so impregnated with hydrocarbons that they may be readily ignited. Unlike sandstone, shales tend to be impermeable to water. Owing to the soft soapy feeling of many deposits of weathered shale the name "soapstone" has been locally incorrectly applied.

There is no part of Kansas in which deposits of shale do not occur at or near the surface. This type of rock, indeed, constitutes approximately 80 per cent of all the sedimentary rocks, from the standpoint of quantity. In eastern Kansas the shale occurs between the limestones, which make more or less prominent escarpments across the state. The thickest of these shale formations is the Cherokee shale, which appears at the surface in Labette, Cherokee, and Crawford counties in the extreme southeastern part of the state. Much of the Permian also is shale, the Wellington formation which outcrops in a broad belt across central Kansas from north to south consisting almost entirely of shale. The Benton division of the Cretaceous is largely composed of shale. The largest single formation of shale in the state is the Pierre shale of upper Cretaceous age, which appears at the surface in the northwestern counties of Kansas. It has a thickness of at least 1,200 feet.

On account of its softness and numerous thin bedding planes, shale breaks down very readily under the action of the weather and forms a soil which ordinarily bears a thick cover of vegetation. The stratified shale is therefore effectually concealed, and good exposures are very unusual. The presence of a shale formation immediately below the surface is commonly marked by smooth slopes or gently rolling topography, for the rock is not sufficiently resistant to erosion to form a prominent feature of the landscape.

Limestone. Limestones are rocks which consist essentially of lime carbonate. Almost all contain more or less impurities such as clay and siliceous matter, those which contain appreciable proportions of magnesium carbonate being known as magnesian limestones or dolomites. Limestones may be fine or coarse grained, hard and brittle or soft and chalky, massive or thin-bedded, and of almost any color. The commonest colors are light or drab gray, yellow or brown. The limestones may be distinguished from other rocks which they resemble by the readiness with which they can be scratched or cut, and by the rather brisk effervescence which is exhibited when they are treated with acid. Limestones are not sufficiently porous in most instances to be of much importance as containers of oil or gas, but some of the limestones of eastern Kansas, notably the Fort Scott ("Oswego") limestone, and the Mississippian limestone in Osage and Kay counties, Oklahoma, and possibly in central southern Kansas, contain important deposits of these materials.

Limestones are apparently much the most widespread and common rock type in Kansas, especially in the eastern part of the state. Beds of limestone, some of them thick, others thin, are found at intervals from the Mississippian almost to the top of the lower Permian, and in the Benton and Niobrara divisions of the Cretaceous. The Mississippian and Niobrara are almost wholly made up of limestone. Quantitatively the limestones are not as important as the shales, but on account of their resistance to weathering and erosion, the limestone beds form more or less prominent escarpments and flat-topped hills. These are the most outstanding topographic features of many parts of the state.

Flint and chert. Flint is a dark gray to black, very hard and compact mass of silica which occurs in irregular nodules and beds in limestone or chalk. Chert, commonly light gray or white in color, is an impure variety of flint which is very abundant in some limestones, as in the Mississippian of the mid-continent region. Both flint and chert are very hard, and although they are brittle and tend to break in sharp-angled fragments, it is extremely difficult to drill through them.

Gradations. All sedimentary rocks are by no means referable to clearly defined examples of one or other of these four main types. Just as some muds are sandy, or sands muddy or gravelly, there are gradations between the main kinds of edimentary rocks. Thus shales may be sandy (arenaceous) or limey (calcareous), sandstones shaly (argillaceous) or imey, and limestones shaly or sandy. A rock composed of nearly equal amounts of sand and clay might be regarded either as a very sandy shale or a very shaly sandstone.

FORMATION OF SEDIMENTARY ROCKS.

DEPOSITION.

Any natural accumulation of gravel, sand, clay, or lime is potentially a sedimentary rock. The geologic agents which make or assist in making such accumulations are the wind, treams, glaciers, lakes, and the oceans. Deposition of the materials which later by pressure and cementation become ocks takes place wherever winds, streams or currents can no longer transport them.

STRATIFICATION.

Since the velocity, and therefore the transporting energy of winds, streams, and lake or ocean currents is by no means contant, the amount and size of the materials which are transported under different conditions and at different times varies. A strong current may move coarse and relatively heavy paricles, such as pebbles, but a gentle current may be able to move only very small particles, as clay. A natural assortment of the materials is thus effected, coarse sediment, as gravel or sand, being deposited in one place, fine sediment, as lay or lime mud, in another. Under changing conditions a layer of fine sediment may be deposited upon coarser material, nd coarse, in turn, on fine. The deposition of sediments in layers in this manner is termed stratification. From the naure of their origin, sedimentary rocks are, typically, stratified rocks, though some rocks, as shales, are much more perectly and finely stratified than others, as sandstones and conlomerates. The planes of division between layers of rock are nown as bedding planes. Not only is each accumulation of ne kind of sediment more or less finely stratified, but the deposition of other kinds in succession upon the first forms a tratification of a larger order. Thus, a formation of limetone may overlie shale, which in turn rests upon sandstone. Sedimentary rocks are well known, therefore, as stratified ocks.

CROSS-BEDDING.

Where particles of sediment are deposited on an inclined surface, as on the lee side of a dune or bar, the fine lines of stratification will incline at the angle of the slope. Since this inclined bedding is not parallel to the main stratification of the formation, it is known as false- or cross-bedding. Cross-bedding is chiefly observed in sandstones. It may be developed in sands deposited by the wind, streams, or lake and ocean currents. The Dakota sandstone in Kansas is locally very much cross-bedded.

PLACE OF DEPOSITION.

On the basis of the place of deposition, sedimentary rocks may be divided broadly into (1) continental deposits and (2) marine deposits.

Continental deposits are those laid down on the lands (*a*) by the winds, (*b*) by streams, (*c*) by glaciers, and (*d*) in lakes or swamps. They are as a whole characterized by the absence of marine fossils and for the most part by irregularity of distribution, thickness, and stratification. Apparently their importance in relation to the production of oil or gas is almost entirely negative, for the conditions which seem to be requisite for the formation of oil and gas are generally lacking. Accumulations of these hydrocarbons, which in some instances have been found in deposits of continental origin, are probably derived from adjacent marine deposits. The "red beds" of upper Permian age, the Tertiary, and at least a part of the Dakota sandstone in Kansas, are evidently continental deposits As indicated by coal beds and very numerous land-plant fossils in the Pennsylvanian and lower Permian, there is evidence that parts of these beds were land deposited.

Marine deposits are those formed in the sea. Such deposits are now being made along the borders of the continents the materials coming primarily from streams which dump their load of sediment and dissolved rock materials into the sea, and from the work of waves which are eroding the lands In the geologic past it is apparent that much of the presen continents has at various times been submerged by the sea for marine deposits are very widespread on the lands. I general, they are characterized by the presence of marine fossils and by the wide distribution and comparative uniformity of character of individual formations. Petroleum and natural gas are so characteristically associated with marine deposits that it seems certain the former is genetically related to the atter. Marine sedimentary rocks are therefore of utmost importance to the student of oil and gas deposits. Most of the sedimentary rocks of Kansas are marine. They include the Mississippian and older Paleozoic rocks not exposed at the surface in the state, and all but a small portion of the Pennsylvanian, lower Permian and Cretaceous.

CHARACTERS OF SEDIMENTARY ROCK FORMATION.

GENERAL STATEMENT.

The important geologic characters of sedimentary rock formation are (1) lithologic character, (2) distribution and hickness, (3) fossils, (4) relation to other rocks, and (5) structure.

SEDIMENTARY ROCK UNITS.

The geological unit among sedimentary rocks is a *formaion.* This may be defined as a sedimentary deposit having more or less similarity in lithologic character and fossils readily identifiable and capable of representation on a geoogic map. It should be a practically useful, as well as a natural division of the rocks. Since sedimentary rocks of a given ype are in many instances graded both vertically and laterally nto a different type, it is in these cases difficult to identify atisfactory lines of division. Consequently, while in most ases a geologic formation consists chiefly of a single rock ype, some formations are composed of a succession of different rock types. Where geologic formations are clearly differentiated by individual distinguishing characters, they are very readily recognizable. However, in such a series of stratified rocks as those of eastern Kansas, which consist of alternating deposits of limestone, sandstone and shale, variable in thickness and extent, and with more or less similar fossil content, *formations* have not been defined in identical manner by all workers—a fact which has caused some confusion in the geoogic study of this region.

Separately identifiable and traceable parts of a geologic formation are in some cases distinguished and named as *members.* The Oread limestone member is a prominent portion of the Douglas formation. In a few instances (in regions where detailed geologic studies have been made) the parts of a member may be separately designated as *beds*. For instance, the Oread limestone member consists of the upper, middle, and lower limestone beds, which are separated by shale beds.

Formations are in some cases grouped together in larger units known as *series*. All the rock formations of a series must be related in geologic age and generally represent the deposits of a single epoch of submergence of the land by the sea.

The deposits made during the larger periods of geologic time are known as *systems*.

Geologic names. The names which are given to geologic formations are derived from a geographic feature — river, creek, hill, mountain, town or county—in the vicinity of which they are typically developed. By agreement the same name may not be used for different formations and the first name properly applied to a formation has priority over names which later may have been employed.

LITHOLOGIC CHARACTER.

The composition, texture, color, and peculiarities of stratification or other features which distinguish a sedimentary rock formation may be described under the head of lithologic character. While this is not entirely constant in all parts of a formation, it is a very important and in most cases a consistent distinguishing feature. Thus the Dakota sandstone of Cretaceous age is in general very readily identifiable on the basis of its lithologic character. It is a brown, rather coarse-grained, massive, extensively cross-bedded and very ferruginous formation, quite unlike most of the other sandstones of the state in appearance. Careful study of lithologic characters may indicate clearly the source of the material in the formation, the general position of old shore lines, and other important geologic information.

DISTRIBUTION AND THICKNESS.

The geographic distribution and the thickness of a formation are matters of geologic significance, since they show the space relations of the formation. All rock formations are typically more or less lenticular in shape, the detailed character of which depends partly on conditions of deposition, and partly, in some cases, on subsequent erosion. A formation of approximately uniform thickness and wide distribution, like most marine limestones, is a reliable datum in the determination of rock structure. A local deposit of very irregular thickness is not a desirable datum. Oil sands are commonly lenticular and more extensive in one direction than another. It is consequently important to know as definitely as possible the horizontal extent and the thickness of the sand.

FOSSILS.

Distinguishing markers of different formations are the fossils they contain. Fossils are the remains or traces of animals or plants which are found in the rocks. Some formations are much more fossiliferous than others, which may be in itself a distinguishing feature; but it has been found that the fossils of one formation are different either in kind or in associations from those in other formations. There are great differences, which are readily evident to the trained geologist, between the fossils contained in formations of different geological ages. This, of course, is a very important aid in the identification of formations and in determining the geological conditions in any area. The fossils found in marine formations are chiefly marine invertebrates and in some cases vertebrates such as fishes and reptiles; those commonly found in continental deposits are fresh-water vertebrates and invertebrates, and land plants. Continental deposits are in general much less fossiliferous than marine deposits.

RELATION TO OTHER ROCKS.

The relation of one rock formation to others with which it is in contact is especially important to the petroleum geologist. This relation is the result of the geologic conditions and history of the region in which the formation occurs. When the sea is gradually encroaching on the land each succeeding formation has a wider distribution than those preceding. The formations then overlap. Many such overlapping series are known. In a continuous series of deposits one formation is normally laid down more or less evenly and regularly upon another, and each succeeding formation is, of course, later or younger in age than those previously deposited. The distinctions between such deposits are the lithologic character, fossils, thickness and perhaps distribution, where a formation is in contact at its base with any rock formation which may chance to underlie it. If a land area composed of various sorts of rocks should be submerged by the sea, the deposit laid down in the sea would cover all the different rocks.

Laterally one rock formation may grade into another of different lithologic character and slightly different fossils, though of essentially the same geologic age. Indeed, this is the normal rather than the exceptional relation, for there is not a sharp line of division between gravel and sand, sand and clay, or clay and lime. Coarse sediments dropped by currents near the shore grade into finer sediments off shore. Consequently a sandstone formation may grade laterally into shale or shale into limestone.

Normally, rock strata are laid down in essentially parallel position, the younger beds regularly succeeding the older. If the deposition of sediment is interrupted, as when the sea is withdrawn from the continent and erosion of the recently formed rock intervenes, not only will there be a gap in the series of deposits, but, especially if the strata are tilted or folded during the change and are beveled off by erosion, the line of contact between the old rocks and those which are later deposited marks a break in the sequence of deposits. The younger beds do not conform to the older and the line of contact is known as an *unconformity*. Unconformities are important in their relation to oil and gas accumulations. Formations which unconformably overlie older beds conceal the structure of the latter.

STRUCTURE.

Sedimentary rocks are originally deposited in a position which is horizontal or nearly so, and the layers or strata are essentially parallel. As a result of warping or folding which has taken place since the time of their deposition, however, the strata may have almost any angle or direction of inclination, in some places even standing in a vertical position. Steep inclinations are commonly found only in mountain areas. The slope of the rock strata in most of Kansas and the mid-continent region is very slight, being measurable only in feet per mile.

Dip and strike. The inclination or slope of rock strata is expressed geologically in terms of dip and strike. Dip is the maxinum angle of slope of a bed from the horizontal. It varies rom 0°, for a horizontal bed, to 90° for those which stand pright. Strike is the bearing of the line of intersection of a orizontal plane and the sloping plane of a stratum. The di-ection of strike is expressed in compass bearings as north 80° vest (N 80° W). The directions of dip and strike are at right ngles to each other. Dip and strike are frequently repre-ented on maps by a T-shaped symbol, in which the upright leg arks the dip and the top the strike. The symbol is so placed n the map that the direction of the strike and dip is indicated y the position of the T, and since the dip line of the symbol oes not show the amount of the dip, this is commonly indi-ated by the proper figure.

Folds. While rock strata are in some places found essen-ially in their original position, that is, horizontal or with a ery slight initial inclination, in most cases they have been ilted, warped or folded. The resulting structures are simple r complex, depending on the nature of the deformation. (1) Iorizontal strata have no dip. Such a structure is technically n *acline* (*a* [no] *cline* [dip]). There are no true aclines of rge size. (2) Where beds are tilted in a single direction the tructure is termed *homocline* (*homo* [uniform] *cline* [dip]). homocline may be gentle and with nearly uniform inclina-ion, or it may be steep and marked by variations in the degree f inclination. (3) Where strata are lifted into an arch or p-fold the structure is termed an *anticline* (*anti* [opposing] *line* [dip]). The sloping sides (limbs) of an anticline may e steep or gentle, nearly equal in slope (symmetrical) or quite nequal (unsymmetrical), and the flexure at the crest sharp, ke the top of a gable roof, or evenly rounded. The crest, or ighest part of an anticline (axis), may trend in a fairly traight line or it may change in direction. It may be ap-roximately the same in elevation along its course, or irregu-rly plunging. An anticline in which the rocks dip in all irections from some point is termed a *dome*. Domes may be ounded, like an inverted saucer, or very irregular in shape. 4) Where the strata are downfolded into a trough-like struc-ure the fold is known as a *syncline* (*syn* [uniting] *cline* dip]). Like anticlines, synclines may be steep or gentle-ided, symmetrical or asymmetrical, and with axes nearly hori-ontal or plunging. Where the rocks dip downward from all sides toward a common point, forming a saucer-like depression, the syncline is termed a rock basin.

In size, folds vary from almost microscopic wrinkles to immense structures many miles in width and embracing thousands of feet of rock strata. Folds vary in complexity from extremely slight warpings, which require careful instrumental measurements to detect, to the bewilderingly intricate, crumpled folds of some mountain regions where it is exceedingly difficult, if at all possible, to trace a given bed any distance. Oil and gas deposits are found chiefly in the more simple structures. In most of the Kansas and Oklahoma folds the maximum vertical distance between the top of an anticline and the bottom of an adjacent syncline is less than 200 feet.

Faults. In some regions the rock strata have been broken and displaced more or less extensively. Such displacements are known as faults. Faults are termed thrust faults when the break is produced by compression, some of the rocks being pushed up and over others. They are known as normal faults when caused by tension or stretching, one side slipping down with reference to the other. The fault planes of normal faults are steeply inclined, those of thrust faults gently. The displacement of the rock strata may be only slight, or in the case of some thrust faults, it may be a number of miles. The rocks of Kansas are almost unbroken by faults, but locally there are small normal faults.

CHAPTER IV.

ORIGIN AND MIGRATION OF OIL AND GAS.

ORIGIN OF OIL AND GAS.[11]

THAT the gaseous, liquid and solid hydrocarbons which occur in petroleum and natural gas are closely related, is vident from the fact that liquids identical with those distilled rom petroleum may be condensed from natural gas; similarly, at the gases given off by petroleum are like those predominatg in natural gas; and finally, that exposure of many petroums to the air results in change to a viscous mass, which on rying becomes a solid asphalt or paraffin-like substance. etroleum is rarely free from natural gas, although the gas ay sometimes be formed alone, as in coal mines or from ecaying vegetation. The question of the origin of these ydrocarbon compounds has great scientific interest as well s a fundamental importance in the economic development of hese materials. It has engaged the attention of naturalists nd others for more than a hundred years and has been the ubject of considerable speculation and no little controversy.

The hypotheses which have been so far advanced for the rigin of oil and gas may be divided into two main categories: 1) the *inorganic,* advanced chiefly by chemists on the basis of boratory experimentation, and (2) the *organic,* held chiefly y geologists and those familiar with the geologic occurrence f oil and gas. The same evidence, interestingly enough, has een used in certain cases by persons holding opposite views. t is not possible or desirable in this report to consider in detail he almost innumerable hypotheses which have been advanced, ut it will be valuable to review briefly the most important.

INORGANIC HYPOTHESES.

That oil and gas may be derived entirely from inorganic ources was first definitely suggested by the French chemist, erthelot.[12] On the assumption that the interior of the earth might contain free alkaline metals, he stated that mineral oil was produced by purely chemical action, similar to that employed in the manufacture of acetylene. Other hypotheses of like nature have been proposed by other chemists, one of the most noteworthy of which is that of the Russian chemist, Mendeléeff.[13] This ascribes the formation of petroleum to the action of surface waters, which, percolating downward through the rocks to the heated interior of the earth, become converted into steam and attack iron carbides to form the hydrocarbons which make up oil and gas. From a chemical standpoint this more or less satisfactorily meets the requirements, but the circulation postulated is questionable and the actual existence of the carbides in nature remains to be proven. For example, if oil and gas were thus formed we should expect to find them most widely distributed and abundant in the oldest rocks of the earth's crust, an expectation which is distinctly contrary to fact. The production of hydrocarbons from cast iron,[14] the formation of various metallic carbides in the electric furnace[15] and various reported occurrences of gaseous and liquid hydrocarbons in association with volcanic emanations and igneous rocks,[16] seem to accord with inorganic hypotheses. The association of oil and gas with igneous rocks is not common, but even in the occurrences known there is no proof that the oi and gas originated in the igneous rock. Admitting that smal quantities of different hydrocarbons may be formed by various inorganic agencies, the evidence seems to indicate clearly that this is not the origin of the large commercially important accumulations of the natural hydrocarbons.

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[11] For a very complete summary of all the hypotheses relative to the formation of etroleum, see Hofer, H. V., Das Erdol, 1906, vol. 1, pp. 160-229; and Engler, C., and löfer, H. V., Die Geologie, Gewinnung und der Transport des Erdols, 1909, vol. 2. eipzig, pp. 59-142. See also, Clarke, F. W., Data of Geochemistry: U. S. Geol. Survey. ul. 616, 1916, pp. 726-737; Campbell, M. R., Historical Review of Theories Advanced y American Geologists to Account for the Origin and Accumulation of Oil: Econ. eology, vol. 6, 1911, pp. 363-395; and White, David, Some Relations in Origin Between oal and Petroleum: Wash. Acad. Sci. Jour., vol. 5, 1915, pp. 189-212, map.

[12] Berthelot, E. M. P., Annales Chem. Phys., 4th ser., vol. 9, 1866, p. 481.

ORGANIC HYPOTHESES.

An overwhelming and increasing majority of those who have studied the accumulated geologic evidence, and who are familiar with the natural conditions under which petroleum occurs are of the opinion that oil and gas are of organic origin. The organic hypotheses suggest that the natural hydrocarbons have been formed by the decomposition of organic matter buried i

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[13] Mendeléeff, D., Ber Deutch. chem. Gesell., vol. 10, 1877, p. 229; Jour. Chem Soc. vol. 32, p. 283; also, Mendeléeff's Principles of Chemistry, Eng. trans., 1891, pp 346-366.

[14] Hahn, Williams and Clofz, Compt. rend., vol. 75, p. 1003.

[15] Moissan, compt. rend. vol. 122, 1896, p. 1362.

[16] Analyses of volcanic gases from Sicily, Santorin and West Indies (Clarke, F. W Data of Geochemistry: U. S. Geol. Surv. Bull. 616, 1916, pp. 263, 268) show the pres ence of methane (CH_4). Basaltic lavas near Ætna contain small amounts of oil an paraffin (Silvestri, O., Gazz, chim. ital., vol. 7, 1877, p. 1, vol. 12, 1882, p. 9, cited b Clarke, loc. cit., p. 727), and the petroleum of certain Javan and Mexican fields is closel associated with igneous rocks. (Clarke, F. W., loc. cit., p. 727.)

ıe rocks, though the precise character of the organisms and
ıe exact nature of changes involved are not entirely certain.
etroleum has been prepared by the distillation of certain
nimal oils and is produced by the natural decomposition of
me seaweeds. It is found chiefly in sedimentary rocks con-
ining more or less abundant fossilized remains of various
ganisms. Gaseous hydrocarbons, especially methane, are
rtainly derived from decaying vegetation, either as "marsh
is" in swamps, or "fire damp" in coal mines. Methane, carbon
oxide, hydrogen and nitrogen are produced in the decay of
aweeds.[17] That hydrocarbons analogous to natural gas,
troleum and asphalt may be derived from either plant or
imal matter or both has been demonstrated. The genesis of
e larger accumulations of mineral oil, however, has not been
oved. The fact that natural petroleum shows an optical
tivity similar to that of sugar, lactic acid and other organic
mpounds, which inorganically synthesized oil does not pos-
ss, is claimed to indicate undoubtedly the organic origin of
troleum.

While the evidence seems to indicate the organic origin of
and gas, there is a difference of opinion as to whether they
ve been derived from accumulations of plants, the remains
animals, or both.

Plant origin. It was held very early that oil and gas were
rived from the natural distillation of carbonaceous matter
ch as the remains of plants in coal. That plants have been
ry abundant in the past is shown by the numerous plant
ssils which have been found in the rocks of almost every
ologic age, including plants living on the land, and others
ınd only in the sea. An apparent relation between oil and
s and certain land plants is indicated by the facts that hydro-
rbons similar to those found in petroleum have been re-
rted[18] in some bituminous coals, and that in at least one
ality in West Virginia gas wells produce from the Pittsburg
il bed.[19] Plant spores, the so-called "algal remains" of
ghead coal, are very abundant in some highly bituminous
petroliferous coals and shales, and may be in some form or

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17. Phillips, F. C., Am. Chem. Jour., vol. 16, p. 427, 1894, cited by Clarke, Data of
chemistry; U. S. Geol. Survey, Bull. 616, p. 729, 1916.

18. Frazer, J. C. W., and Hoffman, E. J., The Constituents of Coal Soluble in Phenol:
S. Bur. Mines, Tech. Paper 5, 1912.

19. Johnson, R. H., and Huntley, L. G., Principles of Oil and Gas Production, p. 19,
6.

other a source of petroleum.[20] Opposed to this it is observed that in general there is a striking lack of any association between petroleum and coal or lignite, that it requires a relatively high temperature, from a geologic standpoint, to convert wood into liquid bitumen without traces of its original structure, and that there is a great chemical difference between petroleum and the tar oils from coal and lignite. It does not seem that terrestrial vegetation would generally give rise to petroleum.

It is possible, in accordance with the arguments of many, that marine plants such as seaweeds are largely the source of petroleum and natural gas. Sea plants along the coasts of Sweden and Sardinia give rise to petroleum as a product of decomposition.[21] As observed in the California fields, oil is very closely associated, in many instances, with deposits of diatoms.[22] The occurrence of petroleum in these diatomaceous deposits is so widespread that the diatom formations have been reliable guides in prospecting—a fact which furnishes the best evidence of the diatomaceous origin of the oil in these districts. Also, the saline water associated with some oils carries iodine,[23] an element characteristically present in sea water. It seems likely that petroleum is at least in part derived fro marine plants.

Animal origin. The theory that petroleum is formed by the decomposition or destructive distillation of animal matter entombed in the strata has many adherents. Under condition easily reproducible in the chemical laboratory, animal matte of almost any sort can be decomposed into mixtures of oil closely resembling petroleum. The chemical processes involv the elimination of nitrogen and nitrogen compounds and a destructive distillation of the fats to form mixtures of hydrocarbons. Since there is indubitable evidence of the former existence of hosts of animal life of various kinds in the strata no containing petroleum, it seems very possible that, at least i part, the natural hydrocarbons are products of animal remain n support of this belief it may be noted that certain petrolifrous beds in Europe are very rich in fossil fish or the remains f mollusks.[24] Shells filled with petroleum have been observed y various writers.[25] The nitrogen bases of certain California etroleums furnish strong evidence that animal proteids conribute their share and are indication of the animal origin f these particular oils. Numerous objections, more or less alid, have been raised against an exclusively animal origin f the natural hydrocarbons. Since limestone is formed almost entirely by the accumulated shells and other hard parts f various sea animals, it might be supposed that oil and gas would be particularly closely associated with such formaions. On the contrary, limestones are in most cases compact nd massive, very ill-suited, except where rendered porous by trong jointing, solution or dolomitization, to act as reservoirs or oil or gas. It has been pointed out [26] that were oil derived rom animal remains to any large extent there should be a ertain proportion of phosphates in the composition of petroeum, since these are characteristic constituents of almost all nimal life. The accumulation and burying of the dead animals in such a manner as to account for the great quantity of petroleum deposits known, is also to be considered. It seems necessary, however, to conclude that in certain cases petroleum and natural gas are largely derived from animal remains of various sorts.

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[20] Jeffrey, E. C., On the Composition and Qualities of Coal: Econ. Geology, vol. p. 741, 1914.

[21] Redwood, Sir Boverton, Petroleum and Its Products, 3d edition, 1913, vol. pp. 132, 148.

[22] Arnold, Ralph, and Anderson, Robert, Geology and Oil Resources of the San Maria Oil District, Santa Barbara County, Cal.; U. S. Geol. Survey, Bull. 322, p. 10 1917. Anderson, Robert, and Pack, R. W., Geology and Oil Resources of the We Border of the San Joaquin Valley, North of Coalinga, Cal.; U. S. Geol. Survey, Bu 603, p. 198, 1915.

[23] Watts, Cal. State Min. Bur., Bull. 19, p. 202, cited by Ries, H., Econom Geology, 4th edition, p. 82, 1916.

OTHER HYPOTHESES.

The statements which have been made at once suggest an ntermediate group of hypotheses which assume a mixed origin for petroleum—animal matter in some cases, vegetable matter n others, or both together. Suggestions of this sort have been made by a large number of writers,[27] probably the most deailed statement being that of Engler and Höfer.[28] This states hat petroleum is derived from the natural decomposition *in*

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[24] Clarke, F. W., loc. cit., p. 730.

[25] Phillips, F. C., On the Occurrence of Petroleum in the Cavities of Fossils: Am. Phil. Soc. Proc., vol. 36, pp. 121-126, 1897. Fraas, O. F., Bull. Soc. sci. nat. Neuchatel, vol. 8, 1868, p. 58. Clarke, F. W., loc. cit., p. 731, 732.

[26] Craig, E. H. Cunningham, Oil Finding, pp. 9, 10, 1912.

[27] Haworth, Erasmus, Kan. Univ. Geol. Survey, vol. 1, 1896; Bownocker, J. A., Geol. Survey Ohio, 4th ser., Bull. 1, 1903; Blatchley, W. S., Ind. Dept. Geol. and Nat. Hist., 28th Ann. Rept., 1904; McGee, W. J., U. S. Geol. Survey, 11th Ann. Rept., 1891, p. 589; Campbell, M. R., Econ. Geol., vol. 6, 1911, pp. 363-395.

[28] Engler, C., and Höfer, H., Das Erdol. vol. 2, pp. 59-102, 1909. See, also, Engler, C., Petroleum, vol. 7, p. 399, 1912; Bacon, R. F., and Hamor, W. A., The Amerian Petroleum Industry, vol. 1, pp. 24-26, 1916.

situ of the fatty remains of marine organisms, both animal and vegetable, and indicates the probable chemical stages of the change. Some contend that oils having an asphalt base are derived from animal matter, and that those having a paraffin base, from vegetable matter, but little can be advanced in proof. It seems clear that under the proper conditions both plants and animals may supply the essential hydrocarbon constituents of oil and gas.

Differences in the quality of the oils are possibly in part due to differences of capillarity, heat, pressure and extent of the migration of the oil,[29] but none of the suggestions along this line have been definitely proved. It has been intimated recently by Richardson[30] that phenomena of surfaces and films, as demonstrated by recent developments of colloidal chemistry, open an entirely new viewpoint for the interpretation of the origin of petroleum. According to this view the origin of all forms of petroleum must be attributed to surface action between a natural gas and the "sands" (using this term in a general sense) with which it comes in contact.

An interesting and apparently a genetically important correlation between the quality of the oil and the degree of deformation of the containing strata has been made by David White.[31] He has shown that in general the oils associated with the low volatile coals are of light specific gravity. This is attributed to the formation of a new very light oil of dynamo-chemical[32] origin, which is contributed to the reservoir, or else to the dynamic transformation of the old oil. White[33] has considered the ingredient materials of coal and oil rocks; the biochemical and dynamo-chemical processes of alteration of the organic detritus; its devolatilization; its regional alteration, and the corresponding regional differences in petroleums, and the occurrence of higher-rank oils in regions of greater alteration of the carbonaceous residues. His conclusions are as follows: (1) Petroleum is a product generated in the course of the geo-dynamic alteration of deposits of organic debris of certain ypes buried in the sedimentary strata. (2) The quantity and naracters of the oils generated are determined by: (*a*) the omposition of the organic deposit at the beginning of alteraon; (*b*) the stage in the progress of this; (*c*) the elimination f the heavier and more viscous hydrocarbons through filtraon incident to migration. It is probable that the composition f the mother organic deposit largely regulates the types of ls; it may account for the nitrogen and sulphur content, olor, etc. (3) The rank of the oils is proportional to the deree of alteration of the carbonaceous deposits. (4) The nange is marked by concentration of hydrogen in the distiltes and of carbon in the residues. (5) Abnormally light oils re in most cases due to filtration. (6) In general, the oils und in successively underlying formations are progressively gher in rank. (7) In regions where the progressive devolalization of the organic deposits in any formation has passed certain point (usually 65 to 70 per cent fixed carbon) comercial oil pools are not present in that or underlying formaons, although gas may occur. (8) Wherever the regional alration of the carbonaceous residues passes the point marked y 65 to 70 per cent of fixed carbon in the pure coals, the light istillates appear in general to be gases at rock temperatures.

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[29] Petroleum can be separated by simple filtration through fuller's earth into fractions which differ in density, viscosity and composition as shown by D. T. Day (Cong. Internat. Petrole, Paris, 1900, p. 53).

[30] Richardson, D., Jour. Ind. Eng. and Chem., vol. 8, p. 4, 1916, cited by Bacon and Hamor, loc. cit., p. 32.

[31] White, David. Some Relations in Origin Between Coal and Petroleum: Wash. Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

[32] The word dynamo-chemical is used to include the action of the heat generated by the pressure as well as the pressure itself.

[33] White, David. Wash. Acad. Sci., Jour., vol. 5, p. 189, 1915

GENERAL CONCLUSIONS.

It may be said that nearly all of the proposed theories to ccount for the origin of petroleum include certain elements f truth; in regard to some of the theories considerable exerimental proof and geologic field evidence has been adduced. ydrocarbons similar to those found in petroleum and natural as may be formed by chemical processes from entirely inrganic sources. The volcanic hypothesis is supported by the ict that hydrocarbons occur among volcanic emanations, and erhaps by the limited occurrence of hydrocarbons in certain neous rocks. As pointed out by Clarke,[34] however, any atmpt to discover the origin of petroleum must take into careıl account the quantitative adequacy of the suggested sources. n this basis it seems clear that in none of the known petroum fields are any of the inorganic hypotheses competent to xplain the origin of the oil and gas. The organic origin of peroleum appears to be best maintained by the geologic relaons of the hydrocarbons and by a consideration of all the factors involved. On the whole, the Engler-Höfer dual theory has the largest number of adherents. Campbell, who has considered the available evidence in a searching manner,[35] states that the testimony favors the animal origin of most petroleum, although a certain amount has probably been derived from the fatty portions of plants. The factors which must be considered are of extreme variety and complexity, and it is doubtful if any dogmatic statement concerning the origin of the natural hydrocarbons applicable to all occurrences can be made.

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[34] Clarke, F. W., loc. cit., p. 735.

MIGRATION OF OIL AND GAS.

Whatever may be the source of petroleum and natural gas and whatever the character of reactions which operate in thei production, it is almost certain that they first appear in a stat of dissemination. If this is true, question must be raised a to the conditions which have caused them to move through th rocks and to accumulate in the pools of varying size which hav been encountered in drilling. These problems will be briefl considered before discussing the geological occurrence of oi and gas.

The movement of oil and gas through the rocks seems referable to five main causes. These are (1) gravitation, (2) capillary attraction, (3) displacement, (4) gas pressure, and (5 difference in specific gravities.

(1) Oil and gas, in common with all other substances, ar affected by *gravitation,* but due to the intervention of mor powerful forces it operates as a cause of migration only unde conditions in which other agencies are relatively inactive Where the rocks are dry and sufficiently porous gravity cause a downward migration of the oil, which is pulled through th pores of the rocks until the spaces between the grains of th rock become too narrow or water is encountered. The movement of oil under the influence of gravity, however, is weak and probably has played a very small part in the great migration of oil which has produced the large oil pools.

(2) *Capillary attraction* is effective in producing movement of oil, and is probably a much more important agent tha gravitation. Capillarity, which may be illustrated by the absorption of ink in the fine pores of a blotter, or the rise o

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[35] Campbell, M. R., Petroleum and Natural Gas Resources of Canada; Canada Dep of Mines, Mines Branch, vol. 1, p. 76, 1914.

erosene in a lamp wick, affects all liquids. The amount of
iovement of oil in the rocks due to capillarity depends on the
iaterial of the rocks, the diameter of the pores, and the tem-
erature. Day[36] has shown that petroleum will diffuse readily
ı all directions through dry clay and shale, the oil becoming
eparated in the diffusion into fractions of different specific
ravities. The migration of the oil depends on the extremely
mall size of the pores, the amount of attraction being in-
ersely proportional to their diameter. Movement ceases
'here the diameter of the pores becomes too great. In the
bsence of water capillarity will draw oil into the fine pores
nd will probably not operate to produce any considerable mi-
ration of the oil. The differential capillary attraction of oil
nd water is, however, as shown by Washburne,[37] an important
actor in causing movement. Since water has a surface ten-
ion almost 50 per cent higher than that of oil, it tends to be
rawn into the fine openings in the rocks with a correspond-
ıgly greater force than that of oil. The water, therefore,
ioves with more readiness from sandstone to shale than in
he reverse direction, while gas and oil tend to move in the
pposite way. The net result is the concentration of the gas
nd oil in the coarsest available spaces in the rocks. As shown
y experiment,[38] water-wet shale is practically impervious to
il and gas, and is, therefore, admirably fitted to serve as a
ap rock, holding oil and gas which have accumulated in a
orous rock beneath. Capillarity is doubtless effective in mov-
ng oil and gas from the less to the more porous rocks, but is
robably not an important factor in the broad migration of
hese fluids.

(3) An effective cause of the migration of oil and gas is the
'isplacement of these materials by agencies which drive them
rom places previously occupied to new positions in the rocks.
)ne of the most important agencies of displacement is the
ompacting of oil- and gas-containing strata by weight of the
verlying rocks. The muds or shales, in which the oil and gas
nay be assumed largely to originate, permit much greater
ompacting than associated sands or sandstones, and the fluid

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[36] Day, David T., The Conditions of Accumulation of Petroleum in the Earth: Am.
hil. Soc. of Phil., Proc., vol. 36, pp. 112-155, 1897; also, Am. Inst. Min. Eng., Trans.,
ol. 41, pp. 212-224, 1910.

[37] Washburne, C. W., The Capillary Concentration of Gas and Oil: Am. Inst. Min.
ng., Bull. No. 93, pp. 2365-2378, 1914; also, Capillarity, Practical Oil Geology, Dorsey
ager, pp. 8, 9, 1916.

[38] Day, David T., loc. cit.

hydrocarbons of the former are squeezed out more or less completely into the porous rocks of the latter type, or along any other line or relief. If joints or fractures are present in associated competent strata there is ready movement along these, but in most cases the only avenue of escape is through the minute spaces between the grains of porous rocks. Since the oil and gas are not regular in their initial distribution through the rocks, and since, due to variation in the weight of overlying beds and differences in the composition and texture of the rocks compressed, the degree of compacting of the strata is not uniform, the squeezing out of the oil and gas is probably by no means the same in different localities.

A second agency of displacement which is probably active in many instances is the reduction of the volume of pore space in the oil- and gas-containing strata by deposition of cement between the grains of the rock. Cementation probably increases as the rocks become more deeply buried, since the load of dissolved material is very much greater in the ground water of the lower levels. In many rocks, even those of very coarse grain, cement may completely fill the interspaces between the grains, making it impossible for them to serve as a reservoir for oil and gas.

A third cause of displacement may be cited in the effect of temperature, which rises gradually with increase of depth within the earth. Since gas, oil, and rock do not expand at the same rate when heated, the expansion of the first and second being much greater than that of the last named, the gas and oil must, in general, be forced upward.

Fluctuations, such as take place in the geologic history of most oil and gas reservoirs, produce repeated changes both in temperature and pressure, which affect the volume relations of the reservoir.

(4) *Gas pressure,* which is probably responsible in large part for the tremendous force with which the oil is expelled from most wells of the "gusher" type, and for the more quiet flow of many other wells, is a fourth cause of the migration of oil and gas through the rocks. As gas accumulates in the rocks its pressure increases, causing it to expand and drive with it any liquid in its path. Pressure in addition to that of accumulated natural gas of the ordinary type is exerted where new gas is formed by dynamo-chemical agencies acting on

ganic matter under the increased heat and pressure of the eper rocks. Such gas is known to be formed from certain the deeper coals, and in the eastern oil and gas fields an parent increase in the proportion of gas to oil and water at creased depths has been observed. This gas pressure will use movement until equilibrium is reached by the capillary traction of oil or water in the fine pores of the rocks or by mpensating hydrostatic pressure. When by any chance the ntaining reservoir of the oil and gas is breached, as by osion, or by a fault, gas pressure may cause the more or ss complete escape of the lighter oil and gas.

(5) *Difference in the specific gravities of water, oil and gas* a very effective and important cause of the migration of and gas through the rocks. As the oil and gas are lighter an the water, they tend to rise to the surface of the water the rocks, and may be raised by the pressure of the water up e dip of the inclined porous beds. Consequently, where the cks are saturated, the oil and gas have been accumulated in e highest part of the reservoir. It has been argued by unn[39] that the movement of the oil and gas is due to the culation of the water, the particles of oil being carried along the water. In many regions, however, there is little to dicate such a general circulation, and the theory has not met th general acceptance. In any case, the presence or absence water in the rocks has played a very important part in the vement and accumulation of oil and gas, and in the study any district it is necessary to determine at the outset iether the rocks are wet or dry.

The movements of oil and gas in the rocks due to the pres- ce of water have been summarized by Campbell[40] in accord- ce with the generally accepted ideas of oil geologists:

> "Urged on by the difference in specific gravity, the oil will rise through interstitial pores in the rock. If the rock consists of a great mass of idstone the oil will be forced to the top of the bed, unless it has been ested in transit by a barrier of impervious sand or clay-sealed fault. ter reaching the top of a particular 'sand,' be it thick or thin, the oil, still forced by the water behind, will seek to escape into the overlying l, but if this bed be composed of impervious clay or shale the oil will confined to the one stratum. When so confined its movement will de-

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[39] Munn, M. J., Studies in the Application of the Anticlinal Theory of Oil and Gas umulation: Econ. Geology, vol. 4, pp. 141-157, 1909.

[40] Campbell, M. R., Petroleum and Natural Gas Resources of Canada: Can. Dept. of ies, Mines Branch, part 1, p. 82, 1914.

pend almost entirely upon the attitude of the bed, or, in other words, upo the geologic structure. If the bed lies nearly horizontal there is mani festly no place to which the oil can migrate, and then it collects in th uppermost layers of the sand. Beds of rock, however, seldom retain thei horizontality for any great distance. If they rise, the oil will tend to mov in this direction, but whether this tendency develops into actual motio will depend largely upon the degree of inclination of the bed. If the di is slight the pressure resulting from the difference in specific gravities o the water and oil may not be sufficient to drive the oil through the ope sand, but in case the bed is sharply tilted the oil will move freely, pr vided that the sand maintains its open character."

ACCUMULATION OF OIL AND GAS.

The agencies which have been discussed in describing th movements of oil and gas through the rocks may, under prope conditions, operate to form at least partial accumulations these materials.

In very porous, dry rocks gravitation may cause a dow ward migration of oil into the lowest available spaces, such the bottoms of synclines, as observed in parts of the We Virginia and Pennsylvania oil fields. In general, however, th conditions requisite for accumulation of oil by gravitation a absent, and as gravity is at best a rather ineffective cause oil movement, concentration by it must be regarded as e ceptional. Capillary attraction, especially the difference capillarities of oil and water, is competent to produce an initi concentration of oil and gas in the coarsest and most poro available strata, but such accumulations are probably in fe cases sufficiently large to be treated as commercial pool Similarly, displacements and gas pressure may produce co centrations of oil and gas, but probably not in importa amounts.

Difference in specific gravities tends to concentrate the g oil and water at definite levels in the rocks (figs. 2, 3, 4 and 7 the degree of the separation depending on the porosity of t rock, and to a certain extent, in many cases, on the motion the materials through the strata. The separation and conce tration due to specific gravities are especially important producing commercial pools of oil and gas, the character of t accumulations depending, of course, on geologic structure a other conditions. It is especially important in the very broa lens-shaped reservoirs which are the largest producers in t mid-continent field. Even where the reservoir has not be ted from the horizontal, the roof is sufficiently inclined in ost cases to permit a separation according to specific gravi- es and hence an accumulation of gas and oil.

OIL AND GAS RESERVOIR.

In the first-discovered fields oil and gas were found in por- is, sandy strata which varied in texture from fine-grained ndstones to conglomerates. These rocks were termed *nds*,[41] and the porous part of the sands containing oil or gas, *ols*. Discoveries in Ohio, Indiana, Illinois, Texas, and re- ntly in Oklahoma and Kansas, have shown that oil and gas ay occur in limestone. Much of the oil from the Bend lime- one of Texas and the Mississippian in northern Oklahoma and e El Dorado district of Kansas appears to come from very rous, cherty beds in the limestone. In a few fields (Florence, lo., and parts of California) the oil has accumulated in fis- ires in shale. In a few recorded instances oil has been found igneous and crystalline rocks, though generally not in suf- ient amounts to be important (Thralls, Tex.). The term ands," as applied broadly to any oil- and gas-containing rock, not, therefore, an accurate lithologic term, although most l and gas accumulations are actually in sand or sandstone.

The name *reservoir* is commonly applied to the sufficiently rous part of the sand or other rock which is capable of hold- g and yielding a commercial quantity of oil or gas if they e present. It includes the whole porous volume of the rock, hether it contains water, oil or gas, or if part of the space dry.

The fundamental requisite of an oil and gas reservoir is rosity. Shales have a relatively slight amount of pore space nd the existing pores are very fine. Therefore, even though shale is saturated with oil, a well drilled into it will hardly tain a showing of oil, because the fineness of the openings the rock hinders the escape of the oil. Limestones are, in e majority of cases, compact and rather fine-grained, con- ining a relatively low amount of available pore space. The ercentage of pore space in average sandstone is higher, but by no means so large as that of most sands and conglomer- tes, because the cementing material which binds the grains of the sandstone together, to a greater or less degree, fill the pores. In average sandstone it varies from 5 to 15 pe cent, while in unconsolidated sands it may amount to 15 or 2 per cent, and in conglomerates to as much as 30 per cent The porosity of the sands and the sandstones varies with number of factors, such as the size of the grains, the uni

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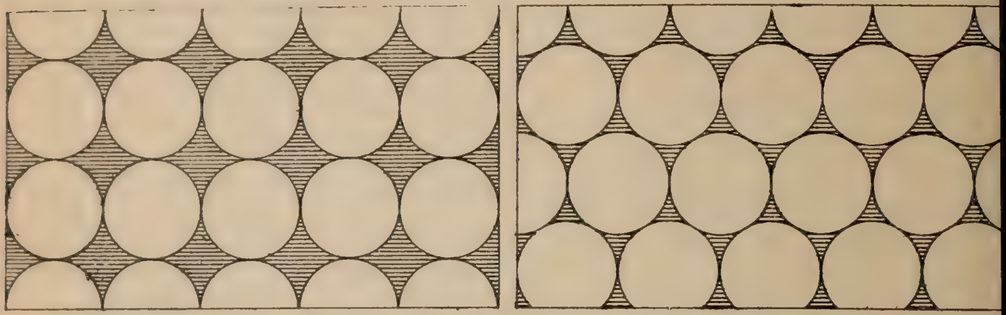
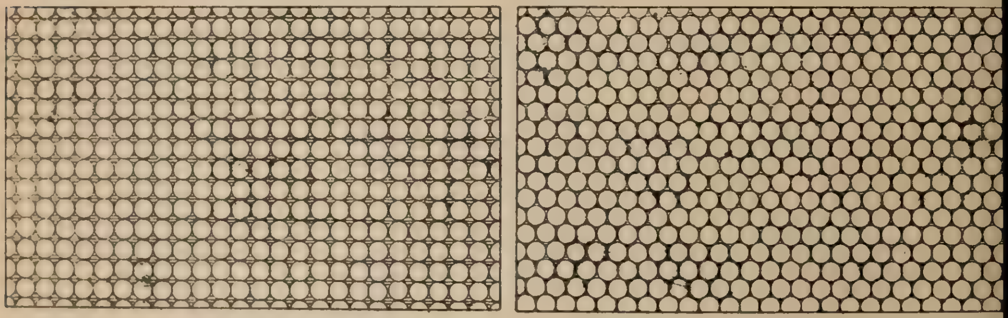
[41] The proper usage of the various terms applied to various portions of oil- or gas- ntaining rocks, such as *sandbody*, *pay*, *pool*, and *oil sand*, have been summarized cently by Johnson and Huntley, Principles of Oil and Gas Production, pp. 39, 40, 57, , 1916.



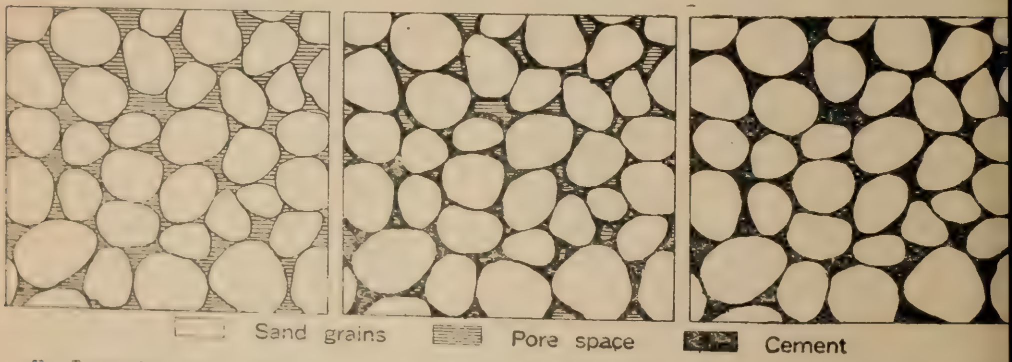
A. Hypothetical rock with large spherical grains, maximum pore space.

B. Hypothetical rock with large spherica grains, minimum pore space.



C. Hypothetical rock with small spherical grains, maximum pore space.

D. Hypothetical rock with small spherica grains, minimum pore space.



E. Irregular grains without cement, showing maximum pore space.

F. Irregular grains with interspaces partly filled with cement, showing reduced pore space.

G. Irregular grains with interspaces completely filled with cement, no pore space

The total amount of pore space in *A* and *C*, or in *B* and *D*, is the same, but a fluid ma be drained much more quickly and completely from the coarse-grained rock.

PLATE IV.—Pore space of rocks.

rmity of their shape, and the amount of clayey matter or
ment between the grains (see plate IV). Spherical grains of
iform size, without any cement, would have a maximum pore
ace; grains of irregular shape and size, with abundant
ment, have a minimum pore space. In case the spaces be-
een the grains are completely filled with solid matter the
ck may be absolutely compact and impervious (plate IV G).
sandstone of this type there can naturally be no commer-
lly important accumulation of oil. Dry, nonporous sand-
one may occur as local "dry spots" in the midst of porous
nd reservoirs containing abundant oil and gas, or dry sand-
one may be extensive enough to separate adjacent pools.
nce lack of porosity is a matter of the rock texture, such
regularities cannot be predicted or defined except by drilling.
There is a not uncommon belief that oil is derived from
derground lakes which are encountered by the drill. From

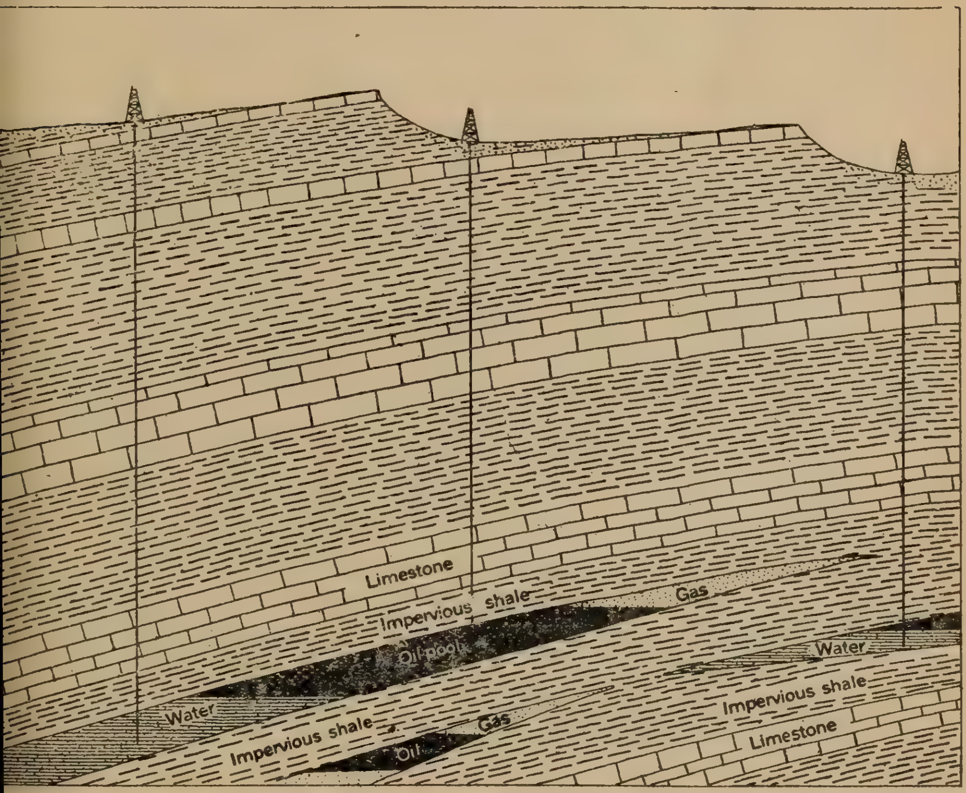


FIGURE 2.—Diagram showing oil and gas in porous lenses.

The gas, oil and water accumulate in the order of their respective
cific gravities, being hindered from escaping by the pinching out of
reservoir between beds of essentially inpervious shale. Notice that
re is no indication in the geologic structure of the existence of such
deposits. The inclination of the beds is considerably exaggerated.

the statements which have been made it is obvious that this is not a necessary assumption with regard to oil reservoirs, as the small pore spaces between the grains of the rock offer quite sufficient room for the accumulation of enormous quantities of oil and gas. Thus, in each 100 cubic feet of a sand containing 20 per cent pore space, 20 cubic feet of oil might occur. An acre of such sand, ten feet thick, would contain, if saturated, 15,553 barrels of oil, and greater thicknesses correspondingly greater amounts. It should be noted, however that the total oil actually contained in a reservoir is never entirely capable of recovery. Indeed, under present methods of extraction, probably not more than 15 to 25 per cent of the oil is, on the average, obtained from the reservoir.

An all-important requirement for the accumulation of oi and gas is an impervious cover or retaining roof which wil hold the oil and gas in the porous reservoir. Such an inclosing cover may consist of almost any very fine or compact rock

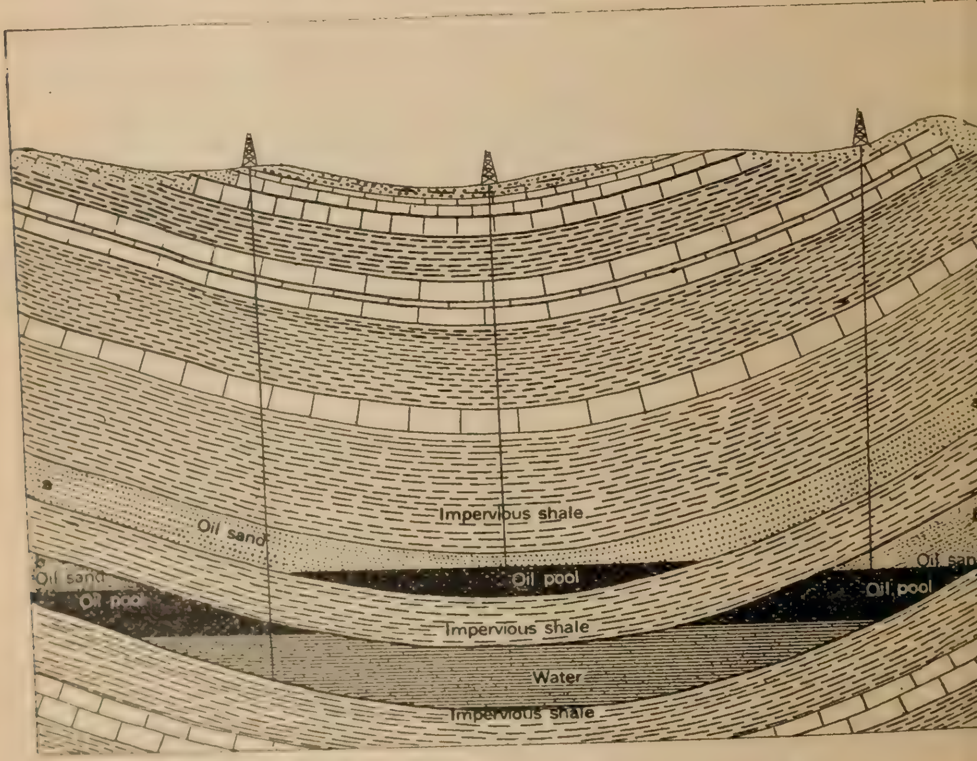


FIGURE 3.—Diagram showing oil in a syncline.

This diagrammatic, geologic cross section shows the occurrence oil in a synclinal fold in which one porous stratum (*a*) is entirely d and in which another (*b*) is partly filled with water. It will be no that in the dry stratum the oil sinks to the bottom of the fold, but i partly filled bed it is floated on the water a certain distance up sides of the fold. The vertical scale is greatly exaggerated.

ch as shale, closely cemented sandstone or dense limestone. the fine pores of the cover rock are filled with water it is e more effective in retaining the contents of the reservoir low. In the absence of a suitable cover the oil and gas will cape from the reservoir, the lighter oil becoming volatilized d leaving behind a heavy residue. The abundant and heavy ales of the oil-bearing strata in Kansas have hindered the cape of the oil and gas, but at the outcrop of certain interdded sands in Missouri (in the vicinity of Higginsville and sewhere) heavy asphaltic deposits have been formed, due to e escape and evaporation of petroleum formerly present in e rocks. Impervious strata occur beneath as well as above ost oil- and gas-containing beds.

The lateral extent of the reservoir rocks is a matter of imrtance. If the sand is lenticular in shape (fig. 2) the pacity to hold oil and gas is gradually reduced in all direcons until at the point where the sand disappears it is zero. such a lenticular reservoir is enclosed between relatively pervious shale beds it may contain a large accumulation of l and gas, even where inclined steeply, the shale at the end the sand serving to retain the oil and gas. A very large umber of the oil and gas reservoirs of the world are of this pe. They are especially common in the mid-continent field.

STRUCTURAL RELATIONS OF OIL AND GAS.

The accumulation of oil and gas has a fundamental relation the geologic structure of the rocks containing them. There rarely, if ever, a sufficient quantity of oil and gas initially istributed throughout a reservoir to permit commercial prouction, and consequently there must be a concentration of ese materials in the reservoir. This further concentration is hiefly due to the geologic structure. In perfectly horizontal trata there is no force compelling accumulation of the oil and as at any particular place in the reservoir rock.

Where the rocks are tilted there is a tendency, which is proortional to the amount of tilting and the degree of porosity of he rocks, for the oil to move along the strata. If the reservoir very dry and sufficiently porous the oil will move downward nder the force of gravity, but if the rocks are saturated with vater, the oil and gas will be floated upward along the stratum.

In the first case, which is exceptional, the oil may become oncentrated at the bottom of a syncline or where water or

some other obstacle is encountered (fig. 3). Oil accumula
tions of this type occur in the folded rocks of Pennsylvania an
West Virginia and in at least one field (Spring valley, Uint
county) in Wyoming. In some instances a small syncline i
filled with oil on account of its position on the limb of a large
anticlinal structure in which the oil and gas are concentrate
Downward movement of the oil tends rather to dispersion tha
concentration.

In the second case the oil and gas are elevated as far as th
water rises. If the water advances only a portion of the po
sible distance, the oil and gas may be partially concentrate
and will not be under pressure (fig. 3, bed *b*). If, however, th
pressure of the water is strong, they will be forced throug
the porous bed until they reach the earth's surface and escap
or until some obstacle is encountered which hinders furth
movement, when they may be compressed to occupy a minimu
of volume.

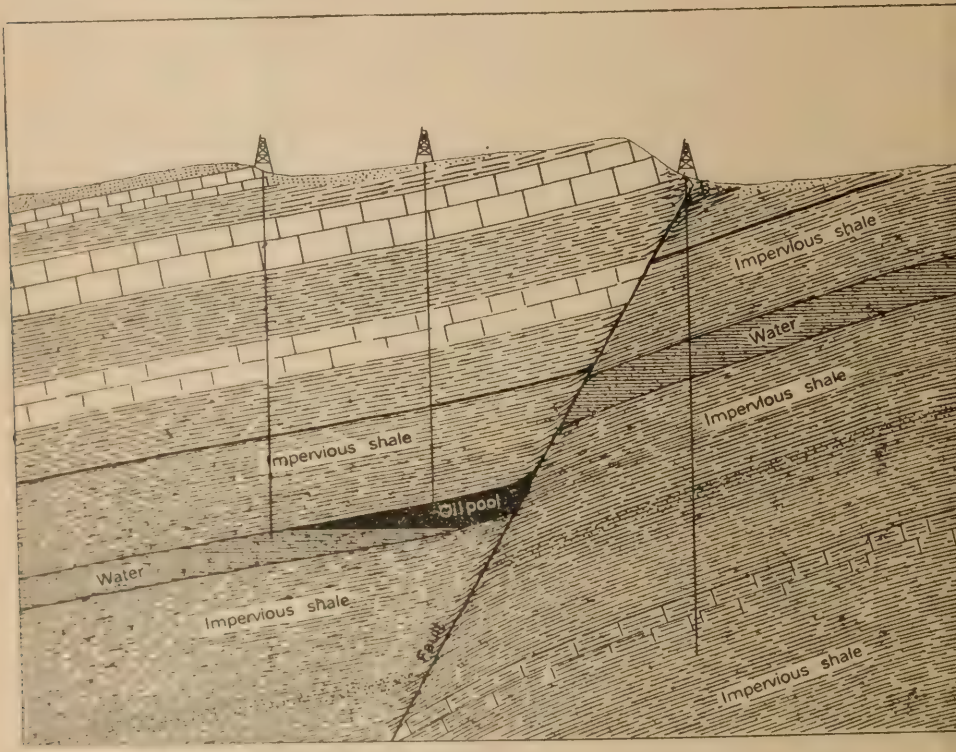


FIGURE 4.—Diagram showing oil sealed in by a fault.

The oil in the porous bed has accumulated above the water, bu
hindered from escaping by the impervious shale and clayey matter w
cut across the oil reservoir. Oil formerly in the stratum to the righ
the fault has escaped. Slight oil seepage may occur where the f
appears at the surface, but a well drilled here has missed the oil pool

The obstacles to unimpeded upward migration of gas, oil d water are various. If the reservoir rock is lenticular in ape the terminal upper portion of the lens will retain the id contents of the rock by reason of the inclosing impervious ds, the gas accumulating at the top, the oil next below, and water occupying the lowermost portion of the reservoir g. 2). In some cases the reservoir stratum is broken across a clay-sealed fault, (fig. 4) or fine-grained igneous intrusion, ich obstructs the movement of the gas, oil and water through rocks, and accumulation takes place in the same manner. iere an oil- and gas-containing bed outcrops at the surface oil and gas may escape, but in some instances the outcrop- ig reservoir is effectively sealed by the very viscous or solid raffin or asphaltic residues which remain in the pores of rock after the partial escape and evaporation of oil. Such arrier may operate effectively to produce a concentration the oil remaining in the reservoir.

By far the most important obstacle to continued movement oil, gas and water along the reservoir, and hence a most nificant cause of oil and gas accumulation is a marked vering of the angle of inclination or a reverse tilting of the wardly inclined reservoir stratum, forming a monoclinal anticlinal fold (fig. 7) or dome.

Under these conditions the oil and gas are raised into the permost part of the structure, where they are prevented m further movement or escape by the impervious cap rock ich overlies the reservoir bed. The gas, by reason of its htness, will accumulate at the top of the structure immedi- ely beneath the cap rock; the oil, having a specific gravity ver than the water, will be separated in a zone or layer be- een the gas and water, and the water will occupy the lowest rts of the reservoir.

In proportion to the sharpness of the anticline and the steep- ss of the inclination of the strata on either side, the oil and s will be concentrated into narrow limits and the pressure ll tend to increase. In some districts in California and rts of the Rocky Mountain fields the oil-containing strata ind vertically, or are even overturned, and the amount of arching or folding may be from 500 to 5,000 feet. In many ses, on the other hand, the anticline is so very broad and ntle, or the structural terrace (monocline) is so poorly defined, that the accumulation is not very effective. In Oklahom and Kansas the strata have everywhere a very slight inclination, and the amount of folding or uplift is rarely more tha 100 or 200 feet. For example, the vertical distance from th top of the anticline to the bottom of the adjoining syncline a Cushing, the most productive pool in the mid-continent fiel and one of the most remarkable in the world, is but 160 fee Such low deformations occur in most cases in a distance of on half mile to a mile.

It should be observed that not all folds, even well-define anticlines in oil regions, are productive of oil or gas. In som cases a structure is thought to be "dry" when the only difficult is in the insufficient depth of drilling. Scores of instanc might be cited from various localities in Kansas where, aft many unsuccessful tests, oil has been discovered in quantity merely drilling to greater depths. Some folds contain ve good oil and gas deposits in certain portions of the structu but are barren in others. This is due to variation in t porosity of the reservoir, the nonproductive part being so lo in percentage of pore space as to contain little or no oil a gas, the productive part showing all the characteristics of t normal porous reservoirs. Such a lack of uniformity in t reservoir is rather the rule than the exception, and the exis ence of a single dry well does not by any means condemn structure. In other instances, however, the structure is abs lutely barren, the conditions having been unfavorable in va ous ways for the accumulation of oil and gas. Some of the unfavorable conditions are: local absence of matter fr which oil and gas are derived, or lack of proper initial con tions for preservation and distillation; lack of porous ro suitable for reservoirs; lack of water to saturate the reserv and force oil and gas to the top of the structure, in which c the oil, if present, will lie on the sides of the folds or in the b tom of the synclines; presence of intrusives or old land m (granite of central Kansas) below the central portion of fold.

SUMMARY.

In summary, the essential general facts with reference commercially important pools of oil and gas may be stated follows: (1) All[42] so far discovered occur in sedimentary ter-laid rocks, such as sands, sandstones, conglomerates, estones and shales; (2) the containing reservoir is porous k, the amount of porosity and size of the pores directly con- lling the possible accumulation and production of oil and ; (3) the reservoir is capped or covered by practically im- rvious beds of shale, limestone or sandstone, similar im- rvious beds in most cases also underlying the reservoir; (4) ter is present in almost all cases in the oil and gas reservoir, l because of its greater specific gravity, tends to occupy the ermost portion of the reservoir; (5) commercial oil and deposits are closely related to the structural character of associated rock strata, occurring for the most part in the her parts of folds, such as anticlines, domes and mono- nes.

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[42] With the exception of the peculiar and relatively unimportant occurrenc Thralls, Tex.

EXPLORATION FOR OIL AND GAS.

The evidences of the presence of petroleum or natural gas ich are commonly noted by geologists, and used by them in exploration of commercial pools and their development, not such as can be properly evaluated by the average lay- n. These may for convenience be divided into (1) direct face indications, and (2) indirect evidences. The former, ich offer the more definite evidence of the existence of oil in rocks, either in the particular locality of their occurrence at a distance, include (*a*) oil seepages, or springs, (*b*) nat- al-gas springs, and (*c*) outcrops of sand impregnated with umen. The indirect are the structural features of the region ich are so important in the accumulation of oil and gas.

DIRECT INDICATIONS.

(1) *Oil seepages* may exist where the outcrop of an oil sand aches the surface, or where there is a crevice or fault through ich the oil may rise to the surface. Seepages are most com- on in the lowlands or along small streams, sometimes ap- aring only as a faint scum[43] on the water. In certain oil gions the occurrence of these scums on the surface of rivers, es and ponds is rather common, but in the mid-continent field seepages are rather rare. The reason for this is that the beds this region are so slightly tilted that for the greater part

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[43] Distinction must be made carefully between true oil scums and those of other stances on water. For instance, iron scum has been very commonly mistaken for roleum, and some operators have invested thousands of dollars on such slight evidence. a rule, where a film of petroleum is present it can be distinguished from that of iron its odor. A small stick thrust into an iron scum will break it up into separate patches, ile an oil scum is so thin and cohesive that it will retain its unbroken appearance and iridescent color.

they remain unbroken, and there have been no means by which the oil could reach the surface except, perhaps, in the minutest quantity. Where the oil-bearing formations reach the surface in the mid-continent field the oil has doubtless already leake away, owing to the fact that the productive strata are of considerable geologic age and there has been ample opportunity during long periods of erosion for the oil and gas to escape

(2) In some oil and gas fields bubbles of gas rise in minute quantities through the water to the surface of streams, and a a few localities there are great *gas springs*. One such spring in the Baku district of Russia is reported to have been burning for thousands of years.[44]

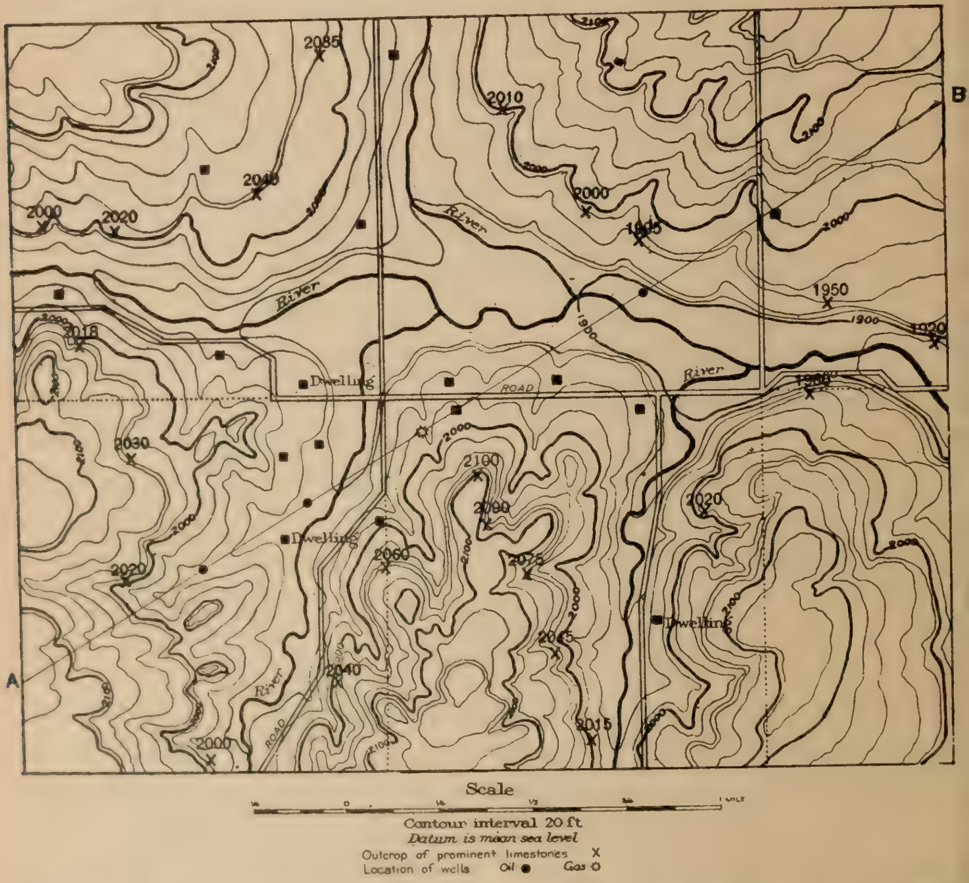

FIGURE 5.—Topographic map of a small area, showing the position and elevation of outcrops of a prominent limestone bed.

The lines, called contours, drawn around the hills are of constant el vation above mean sea level and are drawn at regular vertical interva Thus they show the actual elevation of the country, the shape of the hil and valleys and the character of the slopes. The limestone formati traced by geologists appears at different elevations over the area, indica ing definitely that the strata are not horizontal. A-B shows the line vertical cross section, figure 7.

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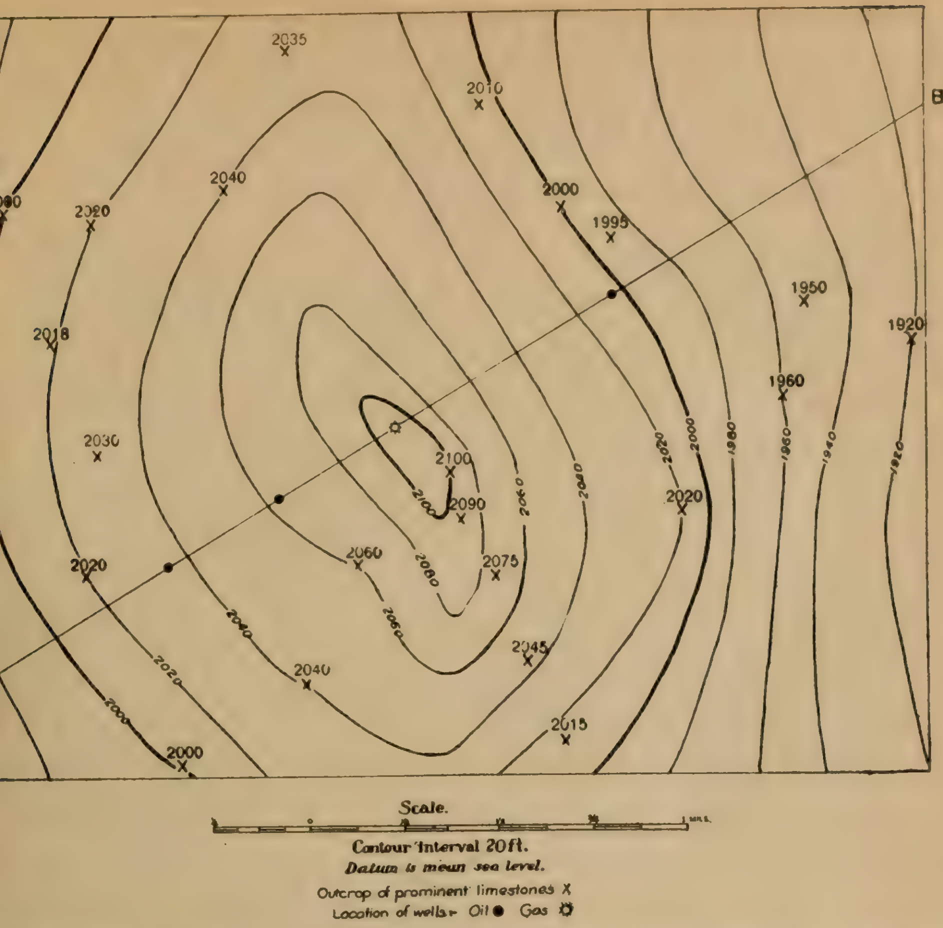
[44] Clapp, Frederick G., The Geology of Petroleum: Am. Petroleum Industry, Bacon and Hamor, vol. 1, p. 36, 1916.



IGURE 6.—Structure contour map of area shown in figure 5, indicating the elevation and structure of prominent limestone bed.

t should be imagined that the portion of the limestone bed which been eroded away (see fig. 7) is restored and that all of the beds rlying the limestone are removed. The surface of the limestone would n appear as a low dome sloping away gently on all sides. If the area re flooded with water standing at 1,920 feet above sea level the conr at this elevation would represent the shore line, and if the water re raised by twenty-foot intervals the successive shore lines would represented in turn by the higher coutours. Thus if the water level re lifted to 2,100 feet only a small island in the center of the area ıld indicate the surface of the limestone bed.

(3) *Outcrops of sand impregnated with bitumen,* the soled tar or asphalt sands, are not common, but exist in several rts of the world. One of the best-known occurrences in rth America is that along the Athabasca and other rivers northern Alberta, in Canada. Recently an asphalt-impregted sandstone has been reported from the vicinity of Hignsville, in Missouri.

These surface indications have certain association with peoleum or natural gas, but commercially important pools of ese materials in many instances lie at a distance from the int where the evidence appears at the surface. For example, where oil, gas or asphalt seepages occur at the outcrop of gently inclined formation the important commercial deposi of oil may exist at a distance of several miles from the expos outcrop. For this reason it is generally inadvisable to dr on or near seepages unless there is evidence that the ma deposit of petroleum occurs directly below. In many cases is possible for a geologist to locate the field from which t oil or gas has escaped.

INDIRECT INDICATIONS.

From what has been said of the conditions governing t accumulation of oil and gas in the porous rock strata it is ev dent that another class of surface indications may be used exploration for these materials. This is the presence of fol ing in the rock strata, which, if pronounced, may be observe readily with the eye. If the folding is very slight it may detected only with the aid of instruments by which the elev tion of the outcrops of given strata may be noted and the dire tion and amount of their dips registered. By studying an mapping these indications of the rock structure carefully geologist is able to define fairly closely the general structu of the underground strata (fig. 6). Hence, if oil and gas a present in the strata at all, the position of their accumulatio with reference to the observed geologic structure may be pr

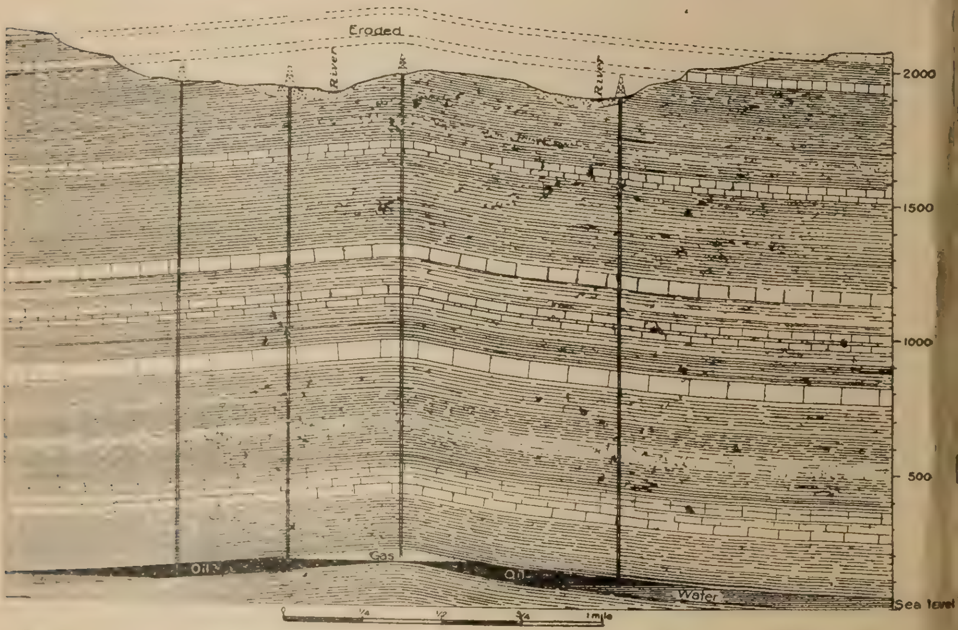
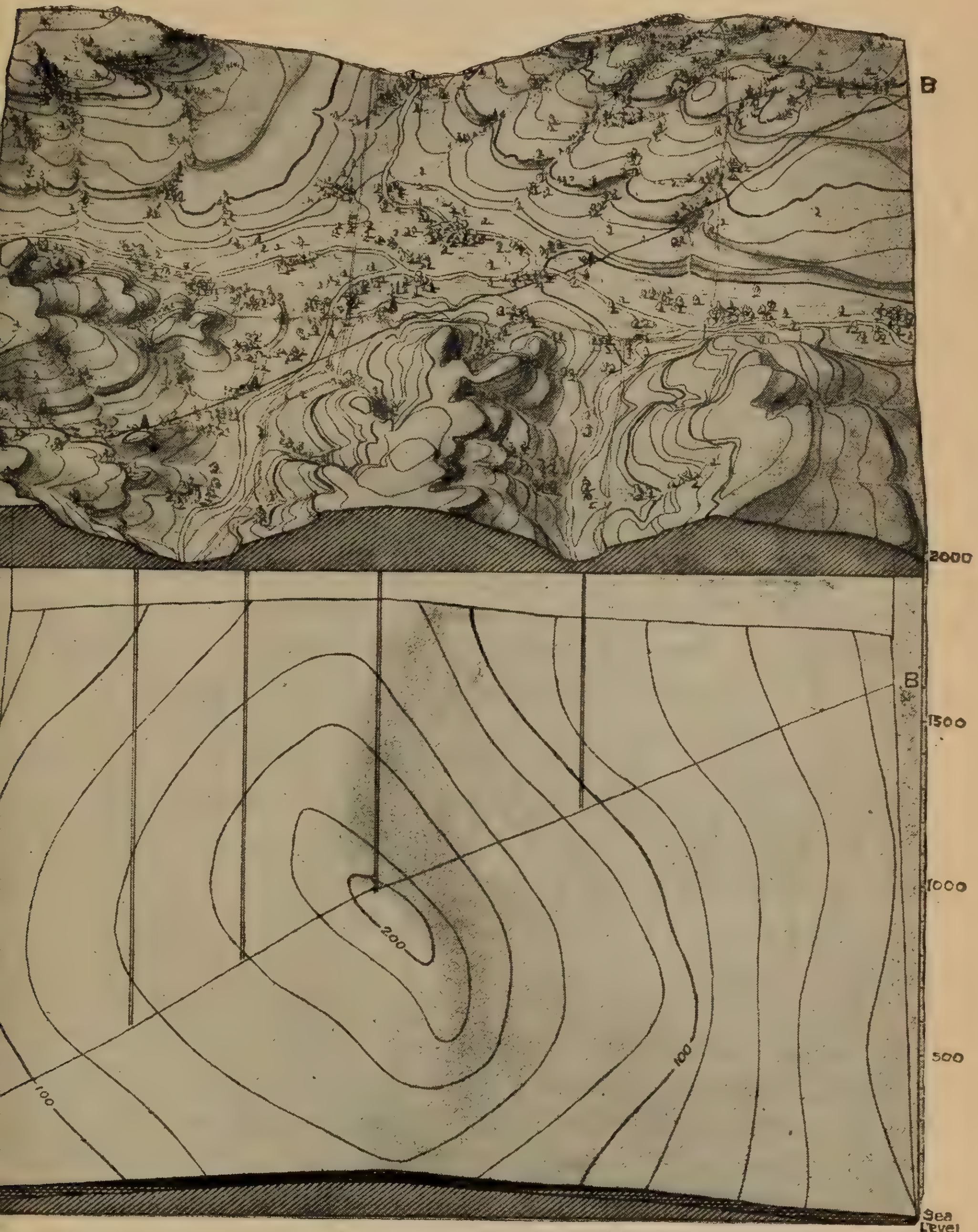


FIGURE 7.—Vertical cross section along line A-B across area shown in figure 5.

The vertical scale is exaggerated about 4½ times.

cted and the most favorable area of probable production def-
tely and scientifically indicated. In the case of a well-de-
ed anticline or dome (fig. 7) the central portion of the dome
uld be most likely to contain gas and oil. Wells drilled on
e sides of the structure would probably strike oil or water.



V.—Stereogram showing surface topography and underground structure of a typical oil and gas pool.

he upper part shows the area mapped in figure 5 and below it a
ntly folded gas- and oil-bearing sandstone layer the structure of which
indicated by observation of the outcrop of a prominent limestone
(figs. 6 and 7). The line of the cross section A-B and wells (fig. 7)
indicated. Notice that the configuration of the land at the surface
not in this case have any relation to the underground structure.

It is evident that the structure of the rocks has little or not ing to do, necessarily, with the character of the surface topo raphy. Thus, the crest of a rock anticline may directly u derlie a valley at the surface. (Fig. 7 and plate V.)

In most oil regions, and especially in Kansas, there are nu erous places where the solid rocks can be found in outcro from point to point over the land. In most cases the ravin and creeks cut into the rocks in their natural bedding, a exposures may also be found along roadways or in railro cuts. These are very important in gathering data for the ge logic map. Indeed, without rock outcrops or other indicati of the character and attitude of the strata, the geologist c do little. In practice, a single prominent bed, such as a lim stone horizon or coal bed, is selected, and the measurements geologic structure are either made directly on the chose stratum or are referred to it. Since the sedimentary rocks the earth are bedded more or less regularly one above anothe the folding of the top layers indicates more or less accurate the folds of the lower layers. Consequently, the structure the key bed at the surface indicates the structure of the oil a gas strata perhaps some thousands of feet below. This rel tion between the rocks at the surface and those deep belo must be understood clearly to appreciate the work of the ge ogist. It should be borne in mind that vast quantities of ro have been removed from the surface of the earth by erosio Ledges on one side of a valley match those on the opposi side, and the beds of one hill those of another. What erosi has taken away must, in imagination, be restored in order form a picture of the original continuous extent of the k layer.

A very common mistake among prospectors for oil and g especially in the early development of petroleum in the Unit States, has been the belief that oil and gas pools run in unifor directions through the rocks. Accordingly, in certain fiel thousands of wells have been drilled along definite lines and given angles from existing pools which were supposed to re resent the position of new deposits. However, pools are no means always arranged in a definite system.

CHAPTER V.

PRODUCTION OF OIL AND GAS.

INTRODUCTION.

HE modern business of oil and gas production is in its
present state a rather complicated and highly developed
ustry. There are many important factors to success, and
large companies are organized with minute attention to
the various details connected with the business.

n the development of a new oil or gas pool, for example, the
logic structure is first located and carefully mapped by com-
ent geologists. Oil and gas leases on the lands overlying the
ictures are obtained, and when all the desirable land has
n secured, drilling rigs are brought in for boring the wells.
en a well is completed and oil or gas encountered, it is
essary to arrange for the storage or the disposition of the
erials obtained from the well, involving the arrangement
pipe-line transportation or tank storage. Large oil com-
ies operating in any of the fields such as those of Kansas
Oklahoma have separate departments devoted to geologic
loration and mapping, leasing, drilling, pipe-line and tank
age, buying, engineering, refining, and marketing.

n the case of an oil strike by any individual or company, the
step of the competing oil operator is to secure leases as
r as possible to the producing well. If he has knowledge of
geological structure of the area he will follow the trend of
anticline or other favorable structure, and if he feels that
properties are within the limits of possible producing terri-
he may make locations and start drilling. In many cases,
ever, land is leased merely because it is in proximity to a
lucing well, and in the rush to newly proved areas many in-
erienced operators, by lack of knowledge both of the nature
he business and of the underground conditions, are led to
ure. It is often the case, however, that the inexperienced
rator, or group of operators, is responsible for the location
ew areas by wells of the "wildcat" type.

should be noted that none of the large oil companies at
sent engaged in operations in any of the large oil fields
wells in entirely unproved territory without any knowl-
e of the geologic structure. A "wildcat" well drilled with-

out any knowledge of the underground conditions, and at a di tance from producing areas, is a speculative hazard of the mos extreme sort. Consequently, in any area which it is desired t test, reference to all geologic advice should be had at the ver outset.

LEASING.

There are no set rules nor any strictly uniform practice i the matter of leasing. As this is necessarily more or less d pendent upon local conditions, the oil men deal entirely wit the individual landowners, and the oil leases are private ba gains. The unit areas of the lease are the simple and unifor land divisions of the civil townships of thirty-six sections int which Kansas is divided. The sections are subdivided int tracts of multiples of ten or twenty acres.

The usual form of oil and gas leases in Kansas grants to th oil producer, or lessee, the irrevocable and exclusive right t seek for oil and gas on the area covered by the lease, the lengt of the lease ranging from one to five years and "as long ther after as oil and gas is produced in commercial quantities." I many instances the lease is taken for a period of five year with option of extending the lease as production continues.

For the right thus given the landowner or lessor is paid on dollar to make the contract legally binding, and in additio such other considerations as may be desirable, varying wit the particular case. The additional compensation to the lan owner may be arranged for in a number of different ways. stated consideration may be paid to the landowner for eac acre as a bonus, depending on the probability of the produ tion of the lease. In many cases the lessee arranges to pa so much rent per year for the lease, thereby holding it until i expires. The most important feature, however, in the compensation of the landowner is the *royalty*, which consists i the payment of a stated fraction of the gross production o profits of wells on the lease. This may, according to state agreement, be paid either in cash or in oil.

In actual practice these various forms of remuneration fo the right to drill supplement each other in various ways according to the agreement of the particular lease. For exampl in a lease where a large bonus is paid, the royalty will probabl be rather low, or if a small price is paid for the lease a larg share of royalty may be exacted. In general, the price an details of the lease contract depend on the nearness to ducing territory and the probability of production in the a leased. In purely "wildcat" regions a bonus is seldom sidered, but in a district which is located near good protion a large bonus may be given. In addition to the custo-ry royalty of one-eighth, bonuses as high as $100 to $200 per e have been paid. In the Cushing field, Oklahoma, in one ance a royalty of 50 per cent was given without bonus.

n the case of producing gas wells the amount and method of ment of the remuneration to the landowner are somewhat iable. On an average, about $100 to $150 per year is paid each gas well, stipulations being made with regard to the of the gas by the landowner and his payment for gas used.

n general, a landowner desires to have a test well drilled at arly a date as possible. Rental leases are therefore somet in disfavor, because the oil operator under these circumnces has the right to drill or not to drill at his pleasure. common rental for commercial leases is $1 per acre per r. In some cases the leases have been so drawn that by payt of 10 to 25 cents per acre annually, after the expiration of first period of time, the lessee may continue to lease for five en years, or indefinitely.

n many leases a time is set for the beginning and comple- of a well, a clause being inserted to the effect that drilling l begin within ninety days or other given time limit, and ompleted to a specified depth within a given period, prong that oil and gas is not found in paying quantities above depth. A clause may also be inserted requiring some sort ystematic continuation of drilling and development of the e. In some cases a bond is required of the lessee as guar- to the landowner of the fulfillment of the terms of the e in payment of royalties, rentals and damages.

n leasing of land for oil and gas the lessor retains all sur- right to the land except on the portion which is necessarily l by the operator for his equipment, including the full ber of wells, power house, boiler house, tankage, waste pit pull rods. Upon an eighty-acre tract not more than five or acres are necessary for this. In a considerable part of the elds the land is not considered sufficiently valuable from an cultural standpoint to make it necessary to place any retions upon oil and gas operations. In certain portions of

the field, however, farmers till the land and at the same tim
derive an income from the oil. Where the land adjoining pr
ducing oil wells contains a growing crop it is agreed that th
lessee is responsible for all damages to the crop, provided the
reach sufficient amount to warrant complaint. Pipe lines shou
be buried below plow depth, but the pull rods from the powe
house to the various wells are sometimes a source of more
less bother because they run just above the ground.

After production has been established the lease becomes on
of the most valuable parts of the oil property. It may be so
or transferred at the option of the lessee, the price dependin
upon the number of producing wells and their average dai
yield. Transfer of leases also takes place even before wel
have been drilled, the price being dependent upon the distan
from proven property. Lease speculation has become a rathe
lucrative business at the present time, especially in new
opened districts. The speculator closely watches the pro
pecting and development, and on news of an oil strike rushes
the locality and leases all available property with as little e
pense as possible. When the operators who really wish
drill come to the field later they are forced to pay the specul
tor's price. Examples of this speculation may be seen in eve
newly opened oil district and have been common in the Kans
and Oklahoma fields. From the standpoint of *bona fide* d
velopment, the operations of the lease speculator are very u
desirable both from the standpoint of the landowner and th
real oil and gas operator.

The recent development in the production of natural-g
gasoline makes necessary provision for royalty to the lessor i
this regard. The average lease is written without such pr
vision.

LOCATION OF WELLS.

After a favorable geologic structure has been located an
leases have been secured, the operator must choose the locatio
of the wells to be drilled. In the case of the first wells the s
lection of sites should be governed as nearly as possible by th
geologic information which is available, the wells being locate
over the central portion of the anticline or dome. Such wel
will form the most satisfactory test of the structure.

In cases where detailed geologic information is lacking,
where the entire area of a lease is likely to be productive, th

ls are placed according to generally recognized rules and rtesies among the operators, or with reference to local conons, such as the nature of the topography. Wells are comnly placed about 200 feet within the boundary line of the se, but this distance varies, with the depth of the sand and er considerations, from 1 foot to 330 feet. Since it is com- practice to lease oil and gas land in multiples of 10 acres, ch equal 660 feet square, there is a tendency, especially in mid-continent field, to put down wells at a distance of 660 from each other. In shallow sands they are located at ater distances apart, about 1,320 feet being an average inal. In large parts of certain fields, like those at El Dorado Augusta, in Butler county, the wells are located with hematical precision in rows and cross-rows. It is custo'y to place the wells on one lease directly opposite those on djoining one, in order to protect property lines and to pre- drainage of oil from the lease. This practice is termed setting."

 practically all of the producing fields many wells have drilled at distances much too close together. In one dis- in Oklahoma probably one-half million dollars has been it on unnecessary wells within an area of two square miles, in the Burkburnett district of Texas the timbers of adja- derricks almost overlap in a number of cases. In the lat- case the division of the land into town lots under different ership has been the primary cause of much of this very teful drilling. No general rule applicable to all districts be given, the proper distance depending largely on cer- local conditions, which must be determined largely by watch of wells drilled later among older wells. If the rvoir stratum is not very porous, gas or oil may drain into well rather slowly and from a limited area. Wells recently ed in the Iola gas field show a surprisingly large produc-, almost equalling the yield of wells first put down. This cates the limited area drained by wells in this district. On other hand, oil and gas may move readily a considerable ance through a very porous reservoir rock. The most ent spacing of wells is really a geological problem, the s of which include the depth to the sand, porosity of the rvoir, character of the oil and other factors in production. hen oil or gas has been discovered in one well there is still urgent need for accurate geologic information for use the location of new wells, that there may be a minimum of c holes and that additional leases secured may be the most pro able.

As a rule, leases are obtained and wells located as close the producing wells as possible, on the strong probabil that the oil and gas reservoir will also be encountered by dr ing on adjacent properties. However, a reservoir usually tends a considerable distance farther along one line than other directions, and a knowledge of the geologic structure a the probable outline of the porous reservoir is all-important the scientific location of wells and in the development of ad cent areas. As soon as an important oil strike has been ma the price of leases in the vicinity advances at an exceedin rapid rate. It is consequently a difficult matter in certain stances to know whether it is better to pay a high price f leases in close proximity to producing wells or to invest lower-priced leases at greater distances with correspondin greater risk. The various factors entering into this conside tion have been studied by Roswell Johnson.[45] A statistical vestigation of a number of pools in the Appalachian field i dicates a rather rapid decline of production in this region f distances from three to six miles from the first well, and more gradual decline at greater distances. So many are t variables, however, that no general statement of this natu applicable to pools in the Midcontinent field can be made. It of course, almost certain that within the general area of a po a number of the wells will prove dry or will contain only wat Consequently, the mere location of a lease in the general ar of an oil or gas pool is by no means a guaranty of oil or g production.

In general the conditions most similar to those observed the discovery well will be observed at the same level in the ro strata in either direction along the strike of the rocks. Th reservoir is likely to persist in this direction and a uniformi of conditions will probably obtain.

Since gas, oil and water in the rocks tend to arrange ther selves in distinct layers in the order of their specific gravitie evident that gas, if present, may be expected in the upper- t parts of the reservoir, oil at points lower down on the dip, water in the lower portions of the porous stratum. Conse- tly, if a well yields only gas, or gas with a little oil, an roducing well may be sought at a point down the dip of reservoir, or if a well encounters water, or water and a oil in the reservoir rock, an oil-producing well is most y to be found higher up in the structure.

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[45] Johnson, Roswell, Efficiency in the Production of Petroleum, in Bacon a Hamor, The American Petroleum Industry, vol. 1, p. 420, 1916; also, Petroleum a Natural gas Resources of Canada: Canada Dept. of Mines, Mines Branch, vol. 1, 325, 326, 1914.

nce the productive pools in a reservoir usually have a ter extent in one direction than at right angles to it, care- bservation of the production and rate of production of the s may indicate to the producer the direction of this axis, therefore suggest the most favorable line of development. pressure persists after a long flow, it is highly probable an undrilled extension of the reservoir exists.

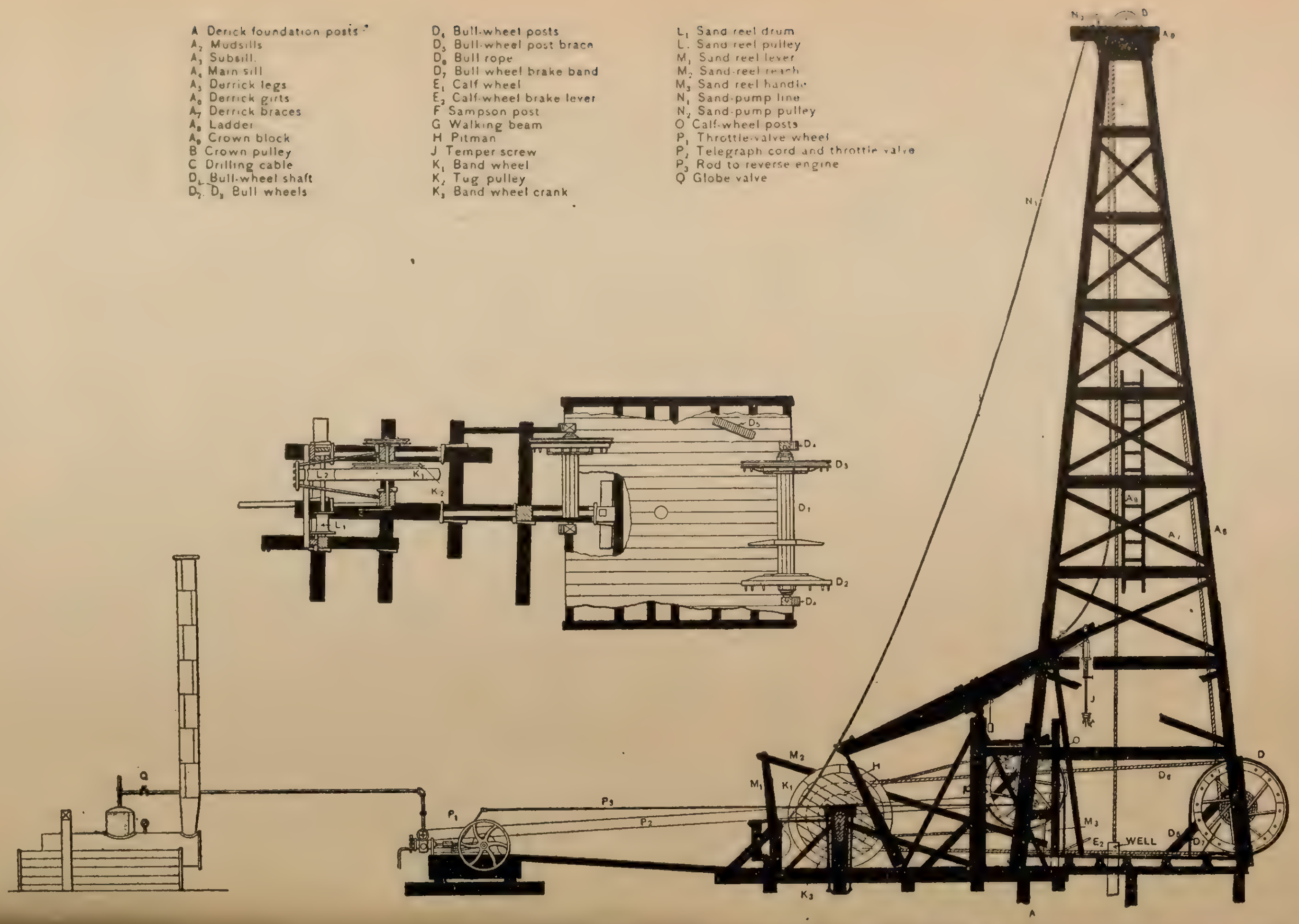
DRILLING FOR OIL AND GAS.

METHOD OF DRILLING.

fter a favorable geologic structure has been found and s have been secured comes the operation of drilling. The ods of drilling are various and have been developed to the particular needs and conditions in different fields. In gion of soft, unconsolidated strata, such as parts of Cali- ia or the gulf coast, the rocks are easily penetrated by a ial type of drill, but in regions of hard strata, such as the continent or Appalachian fields, this drill cannot be used essfully and other methods must be employed.

e system almost exclusively used in Kansas and Okla- a is the so-called "standard" or cable drilling, which con- essentially of a heavy steel bit attached to a manila or cable, which is raised and dropped by means of a walking extending over the hole. It is especially adapted for ing into hard formations or those sufficiently consolidated the sides of the hole will not cave. Under these conditions ing may be continued until it is advisable to case off a r- or gas-bearing stratum.

comparatively shallow territory in the Kansas or Okla- a fields a portable machine of the "Star" or "Parkersburg" is commonly used (plate VIII). These have the advan- of being moved about easily even where roads are bad, less loss of time than a heavy regulation outfit, but



A	Derick foundation posts
A_2	Mudsills
A_3	Subsill.
A_4	Main sill
A_5	Derrick legs
A_6	Derrick girts
A_7	Derrick braces
A_8	Ladder
A_9	Crown block
B	Crown pulley
C	Drilling cable
D_1	Bull-wheel shaft
D_2, D_3	Bull wheels
D_4	Bull-wheel posts
D_5	Bull-wheel post brace
D_6	Bull rope
D_7	Bull wheel brake band
E_1	Calf wheel
E_2	Calf-wheel brake lever
F	Sampson post
G	Walking beam
H	Pitman
J	Temper screw
K_1	Band wheel
K_2	Tug pulley
K_3	Band wheel crank
L_1	Sand reel drum
L_2	Sand reel pulley
M_1	Sand reel lever
M_2	Sand-reel reach
M_3	Sand reel handle
N_1	Sand-pump line
N_2	Sand-pump pulley
O	Calf-wheel posts
P_1	Throttle-valve wheel
P_2	Telegraph cord and throttle valve
P_3	Rod to reverse engine
Q	Globe valve

PLATE VI.—Standard drilling outfit, coupled for raising tools.

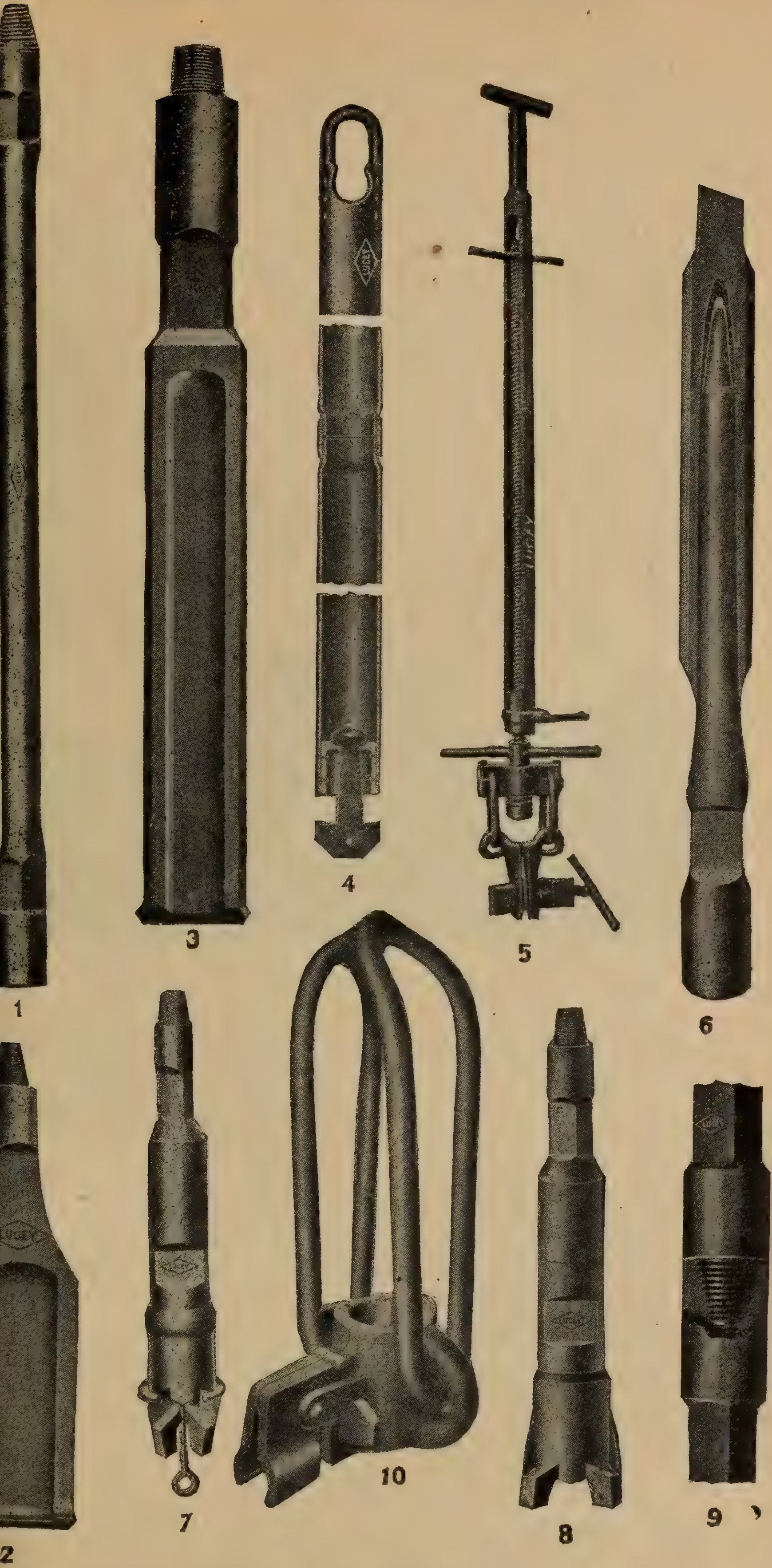


PLATE VII.—Drilling tools.

, Auger stem; 2, spudding bit; 3, drilling bit; 4, bailer; 5 temper screw; rilling jars; 7-8, underreamer, closed and open; 9, joint; 10, elevator, for g casing into derrick. (Lucey.)

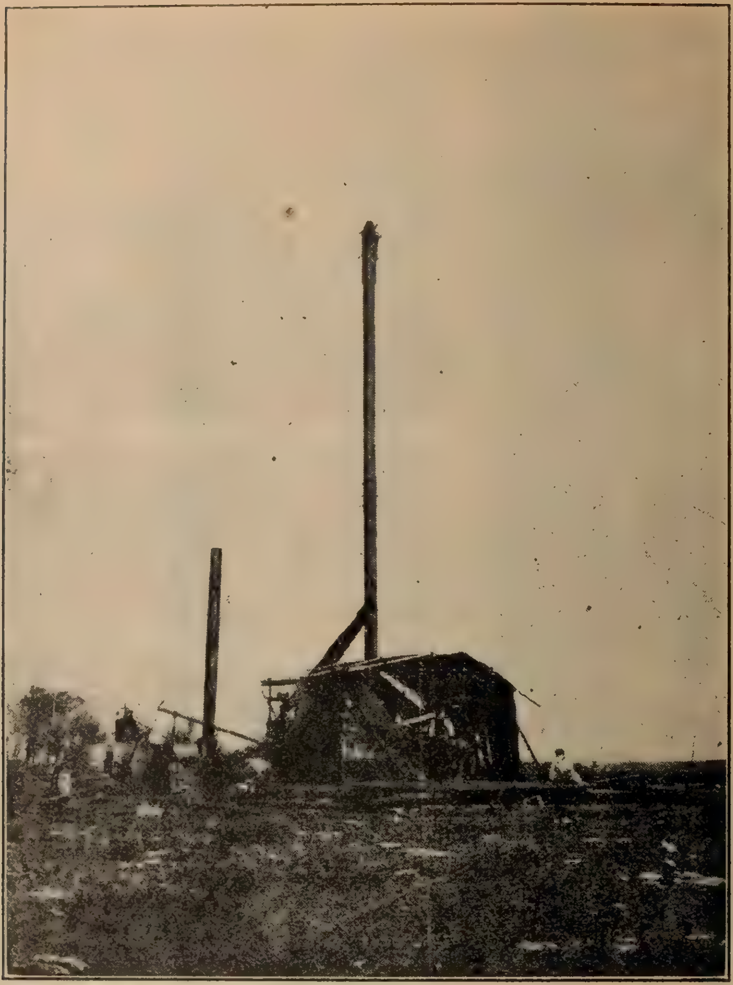


PLATE VIII.—Star drilling rig, south of Sedan.

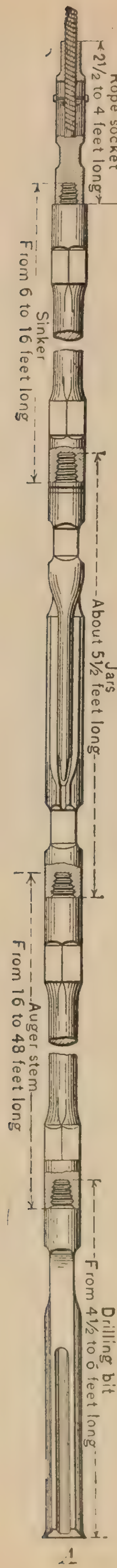
are not adapted for handling heavy strings of tools or casi
The time-saving and the cheapness with which such a machi
can drill a well from 1,000 to 1,200 feet especially adapts it
developing shallow territory.

The site of the well having been selected, the first operati
in drilling is the erection of the rig (plate VI). The ma
portion of this is the derrick, which consists of four stro
uprights converging toward the top, held in position by t
and braces and resting on a strong foundation of concrete pi
or wooden sills. For drilling the deeper wells the derrick is
least seventy feet high, on account of the length of the "strin
of drilling tools, and from twenty feet wide at the base
about four feet at the top. The derrick is surmounted by t
crown block, bearing the pulleys for the drilling cable and t
sand-pump. The parts of the rig actually employed in t

eration of drilling are, in addition to the drilling tools and ble, the temper screw (fig. 8) which grips the cable and justs its length to the depth of the hole; the walking am, to one end of which the temper screw is attached; d the large wooden jack or band wheel, which gives power the walking beam and other parts of the rig (plate VI). e temper screw is gradually turned as drilling goes on, reasing the depth of the tools from the surface. When entire length of the screw, amounting to about five feet, s been let out, the tools are withdrawn and preparations made for the next "run." The walking beam is a mase timber, measuring from sixteen to twenty-four feet in gth, which gives the vertical motion to the cable and ing of tools. It is supported in the middle by the upright nson post and connected at the end opposite the temper ew by a pitman rod to a crank on the band wheel. The tion of the band wheel thus moves the walking beam altertely up and down. The drilling machinery is very simple, t the effectiveness of the drill is due to the peculiar form of drilling tools and the skill used in handling them.

After the tools have drilled the length of the temper screw o the rock it is necessary to draw the tools to the surface and il out the sandy or muddy debris at the bottom of the well. r this operation an entirely different arrangement is necesry, the portions of the rig used being the bull wheel on which drilling cable is wound, the crown pulley at the top of the rrick, and the band wheel which is connected to supply wer to the bull wheel. The bull wheel consists of a reel on ich the drilling cable is wound and an attached wheel on her side, one of which carries the driving belt from the band eel, the other bearing a stout iron band brake by which the eed of the reel may be controlled. The cable, having been sed from the clamps of the temper screw, runs directly to crown pulley from the well, thence down to the bull wheel the side of the derrick, and as the cable is wound on the reel long string of tools is lifted out of the well up into the rrick. When the tools have been thus withdrawn the well is ady to be bailed.

The operation of bailing the well consists simply in lowering sand pump or bailer by a separate line from the sand-reel lley at the top of the derrick, allowing the bailer to fill and awing it again to the surface. The bailer is a plain cylinder



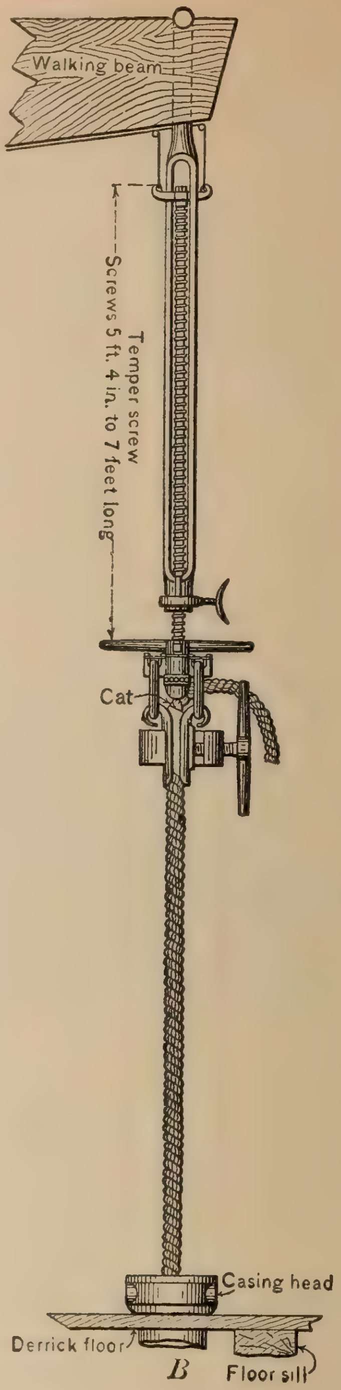


FIGURE 8.—A, String of tools used with standard drilling outfit. B, Temper screw. (After Bowman, U. S. G. S.)

light galvanized iron, with a bail at the top and a stem valve
the bottom (plate VII). As this projects beyond the bottom
automatically fills the bailer when lowered to the bottom of
e waste trough at the surface. The average length of the
iler is about fifteen feet, but some are as long as twenty feet.
hen the well has been bailed it is ready for further drilling.

In some standard rigs, especially those used in California,
additional wheel, known as the calf wheel, is located oppo-
e the bull wheel. It is used for handling casing, and saves
ich time because it obviates the necessity of disconnecting
e tools from the drilling cable and the use of the bull wheel
r this work.

Beyond the derrick and the other parts of the rig is the en-
ne, which furnishes power to the band wheel by a belt. Steam
wer is almost universally used in the drilling of oil wells,
e steam being supplied by a boiler located at a distance from
e well in order to decrease the danger of fire. The engine is
ntrolled from the derrick. Water for the boiler is obtained
om a near-by water well or stream, but in some cases the
atter of water supply is a serious difficulty and greatly hin-
rs or delays the drilling of the well. Some of the wells in
e El Dorado field have recently been drilled using electric
wer, the experiment being apparently quite successful.

The string of tools used in deep-well drilling consists of
veral parts, all of which have certain definite functions and
e the outgrowth of years of experience. A full string com-
ises a rope socket, sinker bar, jars, auger stem and bit (fig.
and plate VII). The socket is used to attach the end of the
illing cable firmly to the drilling tools, the methods of at-
chment varying rather widely in different cases. The sinker
r is a long, heavy bar used to give weight to the drill and to
ep the hole straight. It was formerly thought to be essential
the string of tools, but is now used only in wet holes. The
rs are in many respects the most interesting and important
rtion of the apparatus (plate VII). They consist essentially
a long double link with close-fitting but freely moving jaws,
hich may be compared to a couple of flattened and elongated
nks of chain. The links are about thirty inches long and are
terposed between the heavy iron auger stem carrying the bit
d the upper bar. The principal use of the jars is to give a
arp jar or jerk to the drill on the upstroke so that the bit is
islodged if it has become jammed in the rock. The drill re-

sponds to the powerful upward blow of the jars as they a jerked violently together by the stroke of the walking bea when it will not yield to the slow and relatively steady pull the rope. The jars are not used to drive the drill into the rock such practice at the hands of an inexperienced driller invar ably resulting in serious damage to the links within a sho time. The auger stem (plate VII) gives additional weight the blows that are struck, and also, by increasing the lengt of the drill, helps to maintain a straight hole. The drillin bits are of various patterns, according to the character of th rock that is being penetrated. A short, light bit is used in th preliminary drilling, known as "spudding" (plate VII). A the joints of the string of tools are fitted with taper-scre joints, so that they may be fastened together firmly with a fe turns.

The operation of drilling an oil well as practiced in the mi continent field may be described briefly. After the rig ha been built the preliminary drilling, known as "spudding," i begun. For this a short, light bit is attached to a cable, whic is run through the crown pulley at the top of the derrick an fastened to the bull-wheel shaft. The up-and-down motion t the spudding drill is given by a rope called the jerk line, whic is fastened to the wrist pin of the band wheel and attached b a curved metal slide, called a spudding show, to the part of th cable which extends from the crown pulley to the bull-whee shaft. Spudding is much harder on the derrick than ordinar drilling, because the entire strain comes at the top of th derrick, while in drilling with the walking beam the weigh and jar of the tools is borne by the samson post.

After the hole has been deepened by spudding sufficiently t permit the use of the regular string of drilling tools, this distance amounting on the average to about 75 or 100 feet, th drilling cable is rigged to the walking beam by the tempe screw and the regular work of drilling is begun. The pitma of the walking beam is fastened to the crank of the band wheel and the beam begins to raise and drop the tools at the rat of about twenty-five strokes a minute. In the earlier drilling when the length and therefore the spring of the cable is less, a shorter stroke is used than when the well has been drilled t greater depths.

The operation of drilling is frequently interrupted by the occurrence of an accident, such as the breaking of the cable, ich necessitates the use of fishing tools of various sorts. If fishing is successful, drilling is resumed, but if unsuccessful well must be abandoned, often after weeks or months of or.

CASING.

very important consideration in the drilling of a well is casing, which protects the hole from caving and keeps out er. In many places where the surface material consists of ose sandy clay or similar material, a conductor box or large "drivepipe," is sunk to bed rock. This facilitates the work drilling the deeper portion of the well. The strata in the per portion of a well are, as a rule, made up of alternating ers of hard and soft beds, porous or slightly porous, and er-bearing or without water. Unless the water in the rocks nder considerable head it is welcomed by the driller, for it es the trouble and expense of pouring water into the hole keep the drillings from interfering with the work of the If the water coming into the hole is too great it is neces- y to lower a string of casing from the surface to the first -water-bearing rock below the water-bearing strata. The ing is set very hard into this lower layer and the water may securely shut off by the use of a mud laden fluid which is ed back under pressure into the porous rock and by the of cement. Further drilling necessitates the use of a ller bit which will pass within the diameter of the casing. ther heavy flows of water are encountered they must be ed off in a similar way. As many as eight or ten different ngs of casing are necessary in some deep wells, which pene- te porous, water-bearing strata.

n comparatively shallow territory a well is sometimes led "wet," the water sands not being cased off and the tools ning in a hole in which the water stands high. If the sides not cave, casing may not be put in until the well is finished. lling under these conditions is, however, considerably slower only rarely justifies the saving in labor and expense of ing.

everal varieties of casing are used. Sheet-iron riveted pipe sed in some foreign wells, but in American fields is almost nown. Casing most commonly used in the mid-continent ls consists of sheet-iron pipe of various sizes and weights, ending on the depth of the well and the water pressure it is necessary to withstand. The ends of the sections a threaded, so that one section may be attached firmly to t preceding. The diameter of the casing pipe varies from thr or four inches to more than eighteen inches.

DRILLING CONTRACTS.

For the drilling of a well a contract is made between t operator and a drilling contractor on the basis of a certa price per foot, the amount of which depends on the locality a the depth of oil sand. The rate is fairly uniform in an acti field, but in "wildcat" areas the rate is usually higher. Stip lation is commonly made in the contract for drilling to a spe fied depth, the contractor being held responsible for reachi this depth. The agreement usually calls for the commenc ment of drilling within a given time. The contractor purchas and constructs the derrick, furnishes tools, fuel, water, boil and engine, and hires the drillers and tool dressers. He is he responsible for accidents. Oil or gas which is found during t process of drilling may be used as fuel by the contractor. I general, he is required to handle all the necessary casing, an in case of a dry hole must pull out all the casing possible. Th operator furnishes drivepipe, casing, and whatever rodding o tubing is necessary, provides for the hauling of the pipe an other accessories, except the derrick and driller's tools, an is responsible for plugging a dry well and filing affidavi thereto.

COST OF DRILLING.

The cost of drilling varies notably in different fields, and under certain conditions may fluctuate widely even in the same field. The controlling factors are, in general, the depth of the well, hardness of the strata or other conditions increasing the difficulty of drilling, distance from supply center, and availability of working supplies such as fuel, water, etc. In the case of individual wells the cost may be from 50 to 100 per cent higher on account of unusual underground conditions or accidents. In general, the drilling of an isolated well in the first development of a property costs more than later wells, because many items necessary for the first well may be used a second time in the drilling of adjacent wells.

KEEPING THE LOG.

One of the greatest needs at present in the scientific development of oil and gas fields of the state is good well logs. Every should give the top and bottom of every sand that carries s, oil or water, in addition to giving the distance from the of the sand to the level where the flow into the well is ınd. The character of other strata passed through, espe- lly those of prominent horizons, such as limestone forma- ns and coal beds, should be noted and described as carefully possible. When drilling is begun in a new field the logs, ;h samples of drill cuttings, should be studied carefully by ompetent geologist in order to determine as accurately as ssible the underground conditions and to advise with regard further development. The State Geological Survey may act a clearing house for such information, and may give assist- :e in the correlation of formations, in determining the depth given formations in various localities, the direction of the of the strata and other features. Without care in record- the information obtained by drilling, and without the as- tance of a geologist, the best results cannot possibly be ained.

SHOOTING THE WELL.

Vhen the drilling of a well has been completed in a rather se-textured reservoir rock, or when the production of a well begun to decline, it is common practice to "shoot" the well, harge of nitroglycerine being generally used for the shoot- . The amount of explosive used varies from a few quarts 60, 80, 100 or even 250 quarts, and is placed in specially igned canisters. The canisters are lowered to the bottom of well and discharged by dropping a nitroglycerine "jack iib" carrying a fulminate cap, which explodes on striking torpedo at the bottom of the well. Formerly the percussion was placed with the charge at the bottom of the well and torpedo was exploded by dropping a conical piece of iron— so-called "go-devil"—upon the charge.

t is a matter of considerable importance, as shown in prac- , to locate the nitroglycerine charge in the pay sand rather n to allow it to extend above into the barren formations. he latter are shattered and fall into the pay sand the debris y interfere very greatly with the operation and production the well. The use of too large a charge in the hope of thor- ;hly shattering the pay sand in a considerable surround- area may so disturb and break the barren formations as make the well valueless.

MANAGEMENT OF OIL WELLS.

The problem of management of the oil well involves (1) the method of recovery of the oil, especially as practiced in the mid-continent field; (2) the more or less rapid but continuous decline from the initial production, the typical life history of all oil wells; and finally (3) the manner of handling the oil after it has been brought to the surface.

METHOD OF RECOVERY.

In certain parts of the Kansas oil fields the oil reaches the surface under its own pressure. Wells from which the oil thus flows are known as "gushers," and, especially when the pressure is very great, are much the most spectacular part of an oil field. The oil does not long continue to flow under its own head, even when the initial pressure is very great, and it then becomes necessary to pump the wells. The great majority of wells in the Kansas oil fields are of the pumping type, the method of pumping, however, varying greatly in different cases. Some wells are pumped by motive power—steam, gas, or gasoline engine—which is located at each well. This demands a separate power unit for each individual well. In other cases a central power plant supplies steam or compressed air to a number of pumps operating wells located around the plant. The central plant may be connected with the individual pumps by shaft or pull rods, which are so fastened to the operating drum at the plant as to compensate one another and make a minimum load on the engine. At the wells are pumping "jacks" of various design which convert the horizontal pull of the rods to a vertical movement of the sucker rods in the well.

INITIAL PRODUCTION AND DECLINE OF OIL WELLS.

It is impossible to determine in advance, with any degree of accuracy, the life of an individual oil well, but it is possible, by means of accurate records of the history of wells, and of the pool containing them, to obtain an approximate estimate as to the length of time during which the well or pool will be productive. A record of the production of an oil well always shows a maximum yield at its very beginning or immediately after a successful shooting of the well. This is known as "flush production." The production then drops off, suddenly at first, and then declines more gradually into "settled production." Minor irregularities in the plotted production curve may be to the influence of neighboring wells or special conditions. n most cases a record of the production of an oil field as hole shows a gradual rise to a maximum, followed by a dual decline. The increase in production at first is, of rse, due to an increased number of wells as the field is de- ped. When the declining production of wells already led is not compensated by production of new wells, the l production of the field begins to decline.

he large initial production of many oil wells is evidently to the strong pressure in the oil reservoir when the wells drilled in. The duration of the period of greater produc- depends upon local conditions, such as the porosity and cture of the sand, the development of the pool, the position he well, and the character of the oil. With the decline in ssure, production gradually decreases in many districts to airly constant amount. Decreased production is due to ine of gas pressure, decrease in quantity of oil draining into area affected by the well, and perhaps by fooding either alt or fresh water from adjacent strata. The drilling of by wells, defects in the setting of the casing, and failure lean the well may be contributary causes to the decline.

ffective management of an oil well is aided by a carefully ted record of the production of the well. This curve gives irly definite idea as to the yield which may be expected, indicates the probable future history of the pool.

THE HANDLING OF OIL.

fter the oil has been brought to the surface, either by ral flow or by pumping, it is necessary to store it near the or to arrange for transportation to a point where it can be l. Where the wells are some distance from a pipe line or n the railroad it is usually necessary to have large storage s where the oil can be kept until its further transportation. storage tanks are usually of steel, and rest like huge cov- tubs on the ground. The largest size used in the mid-con- nt field is the 55,000-barrel tank, which has a diameter of t 115 feet and a height of 30 feet. There are 30,000-barrel s, diameter 86 feet, height 30 feet; 20,000-barrel tanks, neter 70 feet, height 30 feet; 10,000-barrel tanks, diameter eet 7 inches, height 30 feet; 5,000-barrel tanks, diameter eet, height 20 feet; and even smaller ones for temporary age. These figures for the capacity and dimensions of oil storage tanks are, of course, subject to a variation dependin on the local conditions. Recently, large storage tanks of concrete have been constructed underground. Greater storag capacity and smaller losses by fire and evaporation are advantages claimed for the reservoirs of this type. In the case o a well of the gusher type it is frequently impossible to get sufficient tank space to store the oil, at least during the time o maximum flow. In this case earthen embankments are buil and a large temporary reservoir constructed. Of course, i open-air storage of this sort there is a very large loss due t evaporation and to the dissipation of the lighter volatile constituents of the oil. It is therefore economical to have a air-tight sealed-roof tank; but under the conditions of th gusher some loss by evaporation is unavoidable. At the refineries are a large number of storage tanks of various sizes and types, both for crude oil and for various refined products. Before the oil is pumped to storage it is usually measured in small gauging tanks 25 to 100 barrels in capacity. Where the oil is kept moving daily large storage tanks are unnecessary.

TRANSPORTATION.

Crude oil is transported either by pipe line or by tank car. At the present time pipe lines are being constructed almost as rapidly as refineries, and it is almost impossible, therefore, to give up-to-date information.

Pipe lines which have been well established are shown upon the general index map (part III). Wells in Texas and Louisiana belonging to the Gulf district are connected by pipe lines through Oklahoma with the region about the Great Lakes and eastward to the Atlantic coast. The pipe used in these lines is about eight inches in diameter, that in diverging branch, large main lines, six, four and three inches in diameter. The crude oil is forced through the pipe from one pumping station to another, and is conducted underground from the oil wells directly to the refinery. The most extensive system of pipe lines in the mid-continent field—probably the largest in any part of the country—is that of the Prairie Oil and Gas Company. This was the first company to begin operations in Kansas, when in 1893 a short line was built connecting the oil wells at Thayer, Kan., with a small refinery at Neodesha. At the present time there are a great number of independent refineries, which in most cases operate their own wells. Acngly, there is an unusual development of short pipe lines 1 connect the refineries with adjacent producing pools. may be shipped to the refinery in tank cars, but at nt little is transported in this way, because in most cases roduction of a pool is sufficient to warrant the laying of e line. The chief use for tank cars is in the transporta- f the refined products from the refineries. The cars vary pacity from 3,600 to 12,500 gallons. Many of the refiner- vn their tank cars, but in some cases they are leased.

FIRE PROTECTION.

ere large quantities of oil are stored, either in the field ar refineries, there is always danger from fire. This may e either to artificial causes or to lightning. Proper in- on of the tanks is usually sufficient to safeguard them danger of ignition by lightning, and proper rules for em- es will usually control the danger from artificial causes. however, possible to extinguish fires which have started ks or oil reservoirs by means of chemicals and apparatus can be installed easily. The general principle of such xtinguishers is either to form a blanket of gas or foam he burning liquid, which excludes the oxygen of the air, dilute the burning liquid with a non-inflammable agent, as carbon tetrachloride, which extinguishes the flames. of the foam-producing mixtures have been particularly ve.

REFINING OF PETROLEUM.

re or less successful refining of petroleum was in practice the eighteenth century, but so great has been the ad- in petroleum refining methods within the last few years efineries seem to be only a recent development. The number of refineries which have been completed within ecent years indicate the great importance of the refining ry. The large number now in construction shows its ued rapid development.

REFINING METHODS.

t of the refineries in the mid-continent field are equipped apparatus for the production of naphtha, illuminating nd fuel oils. Some of them are prepared to distill the als and produce lubricating oils, paraffin, and other prod- The general procedure at the refineries is about as s: Crude oil is admitted into the storage tanks along the pipe lines or received by rail from the tank cars. The o is then run into the still and distilled by fire heat or by combination of fire heat and superheated steam. The vapo from the still are carried into a condensing arrangement, abou which is a cold-water jacket, and the liquid product run into tank. Many of the large refineries distill petroleum by th “continuous system,” in which the stills are connected an operated in a continuous manner. By firing successive still to higher temperatures, fractions with successively highe boiling points are obtained simultaneously.

The chief methods of distillation are[46] (*a*) the “dry” destructive or distillation “cracking” process, used when a large yiel of gasoline and illuminating oil is desired; (*b*) fractional distillation; (*c*) vacuum process; (*d*) pressure distillation.

(*a*) *“Dry” or “cracking” distillation process.* In this process the heavy vapors from the crude oil condense in the to of the still and fall back on the superheated oil, and are thus “cracked” or partially decomposed. The first of the products to form is naphtha or benzine. In the destructive distillation of a paraffin-base petroleum the flow begins at about 80° Baumé gravity, the product being termed “light naphtha.” The next distillation is from 69° to 58° Baumé, and is known as “heavy naphtha.” The third fraction, which is generally called the “high-test burning oil,” is collected from 58° to 43° Baumé. The fourth fraction is known as “low-test burning oil” and is collected until the residue in the still reaches 21° or 22° Baumé. Fractions 3 and 4 are usually redistilled in steam stills, and yield “burning-oil distillate” and “burning-oil stock.” The residue is called tar, and contains the paraffin oil and paraffin wax. It is distilled to dryness, yielding “paraffin distillate” and “wax tailings,” coke remaining behind. The proportion of the various products from this dry distillation is on the average as follows:

Light and heavy naphtha (gasoline)	12 to 15 per cent
Burning-oil stock	65 to 75 per cent
Tar	10 to 12 per cent
Loss	5 to 6 per cent

The temperatures at which the chief refinery products are derived in the “cracking” distillation of Kansas petroleum are as follows: When the temperature of the oil in the still is dually raised from 200° F. to 325° F., about 6 to 8 per cent rude naphtha (boiling point 200° F.) is distilled. With a dual increase from 325° to 475° F., 13 to 15 per cent of the de heavy is distilled; and to about 625° F. a "natural lamp illate," representing 16 to 18 per cent of the crude petro- n, is obtained. The destructive distillation known as "crack- " begins at a temperature of about 625° F. The cracking arried on very slowly, until at 700° F. a distillate called the s and fuel-oil stock" is produced. This contains some oline, lamp oil and heavier oils, and has an average boiling nt of about 550° F. It comprises about 20 per cent of the ginal crude petroleum. The residue left in the still at this perature is a heavy black tar, about 42 per cent of the de oil.

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[46] For a complete account of petroleum refining methods, see Bacon and Hamor, American Petroleum Industry, vol. 2, 1916.

(*b*) *Fractional distillation.* In the manufacture of lubri- ing oil from paraffin-base petroleum, "dry" steam is intro- ed into the oil. The hydrocarbons are then distilled at peratures below normal boiling points, because the partial ssure on the hydrocarbons is less than that of the atmos- re.

(*c*) *Vacuum process.* In some refineries a vacuum process sed in combination with (*b*). It consists in the creation of artial vacuum in the still, so that the hydrocarbons are tilled at temperatures considerably below their boiling nts at atmospheric pressure.

(*d*) *Pressure distillation.* Several patented processes which olve pressure and high temperatures are now in use in the duction of gasoline from gas and fuel oils. These "crack- " processes are too complex to be discussed here.[47]

PETROLEUM PRODUCTS MANUFACTURED IN THE MIDCONTINENT FIELD.

enzine. The raw condensate distilled from crude petroleum m the lightest fraction to about 52° Baumé gravity.

asoline. This includes many steam-refined products from benzine. Three grades of gasoline are produced in Kansas l Oklahoma—68° to 70° Baumé, 64° to 66° Baumé, and 61° 63° Baumé. The last two grades are those ordinarily used in omobiles.

---

[47] Bacon and Hamor, op. cit. pp. 554-579.

Naphtha. The portion of steam-refined benzine of grav heavier than gasoline, showing a gravity of 50° to 58° Bau

Kerosene. Including the heavier fractions, showing a gr ity of 52° to 36° Baumé. These condensates are chemica treated with sulphuric acid and caustic soda. Several gra of kerosene and naphtha are manufactured by various fineries.

Fuel oil. This is an indefinite term, and there are no spe fications for mid-continent fuel oils. It must not cont gasoline and many customers require that it be of such c sistency that it can be pumped through pipes and burners.

Road oil. An indefinite name, covering grades of oil us chiefly as a dust preventive, ranging from 34° Baumé to asphaltic material which is solid at 60° F. Several grades road oil are produced from Kansas petroleum.

Lubricating oil. A great many grades of lubricating oil a produced at some of the refineries. Various companies ha their own trade names for the different grades of these lub cating oils. In 1916 there were six refining companies Kansas listed as producing lubricating oils.

The refining of crude oil has undergone great changes du

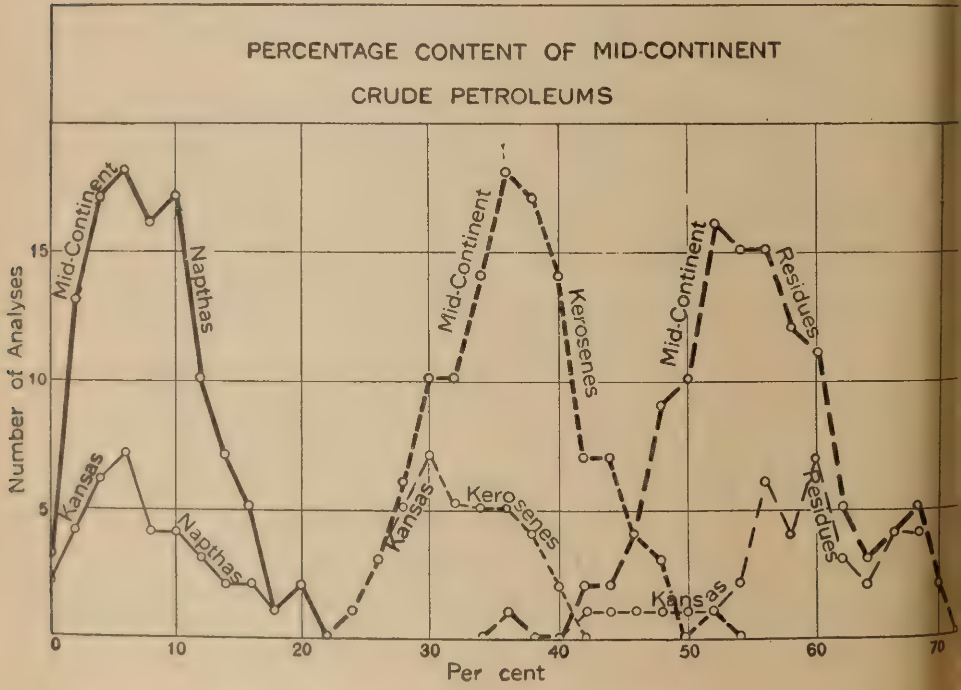

FIGURE 9.—Average mid-continent crude petroleum contains 5 to 1 per cent naphtha, 34 to 40 per cent kerosene, and 50 to 60 per cen residues.

the past two years. Undoubtedly one of the chief factors s been the very rapidly increasing demand for gasoline. In 15 average motor gasoline ranged from 60° to 64° Baumé. at generally used at this time has a distinctly lower gravity. ry little 60° to 61° gasoline is sold, the average being from ° to 56.° This heavier fraction, formerly called naphtha, is w included in gasoline. It is realized, however, that degrees umé gravity do not necessarily indicate the quality of the soline or oil produced. It has been demonstrated that a 57° oduct may be just as good or better than a 60° product from other oil which has been treated in another manner.[48]

NDENSATION OF GASOLINE FROM NATURAL GAS.[49]

Mention of natural-gas gasoline is not out of place here. ider a compression of 350 pounds, casing-head gas yields om one to four gallons of "wild" gasoline per 1,000 cubic et of gas. In practice, commercial plants produce from one d one-half to three gallons. The gasoline produced is in any cases higher than 88° Baumé, but it is allowed to veather" to this gravity before being shipped to a refinery r blending with low-grade naphtha.

A new process, in which gasoline is absorbed in oil, makes it ssible to treat great quantities of gas rapidly. The oil, with absorbed gasoline, circulates through a continuous still, in hich gasoline is driven off and condenses separately, the oil ing back to the absorbing apparatus.

The gas gasoline is sold to refineries to be blended with low-ade naphthas in the production of commercial-grade gasoline, is used in various chemical industries. Because of its very ght, volatile character, gas gasoline is very valuable in the oduction of highest-grade motor spirits for aeroplanes and her powerful gasoline engines. Kansas led the United ates in 1919 in percentage of increase in the production of tural gas gasoline.

---

48. An illustration of this is given by Mr. H. G. James, president of the Western troleum Refiners Association (James, H. G., Refining Industry of the United States, errick Publishing Company, Oil City, Pa., 1916): "Taking a 40° gravity Cushing crude, first-class 58° gravity gasoline is made by starting the initial at 125° F. and cutting the d point at 410° F. Now let us suppose the initial of this same end point is 140° F., d the end point 460° F., you will secure a larger quantity but a far inferior product. other words, a 58° gravity gasoline, as first described above, is a much superior ticle to a 60° or 61° with an initial of 130° F. and an end point of 435° F.

49. Johnson, R. H., and Huntley, L. G., Oil and Gas Production, chapter XVII, 16.

[illegible] M Riley

STATE GEOLOGICAL SURVEY OF KANSAS
RAYMOND C. MOORE, State Geologist

OIL *and* GAS RESOURCES *of* KANSAS

PART II

GEOLOGY *of* KANSAS

By RAYMOND C. MOORE

BULLETIN 6

Printed by authority of the State of Kansas

PRINTED BY STATE PRINTING PLANT
IMRI ZUMWALT, STATE PRINTER
TOPEKA, KANSAS

Publications of the State Geological Survey are distributed from
Lawrence, Kansas.

8-9820

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CONTENTS.

OGY OF KANSAS.

PAGE
- Introduction 7
  - Formation of the rocks of Kansas 7
- Older rocks of the Midcontinent region 9
  - Pre-Cambrian 9
  - Cambrian and Ordovician 9
- Mississippian system 12
- Pennsylvanian system 14
  - General description 14
    - Distribution 14
    - Lithologic character 15
    - Effect on topography 16
    - Structure 17
    - Subdivisions 17
  - Des Moines group 19
    - Cherokee shale 20
    - Marmaton formation 23
      - Fort Scott limestone member 25
      - Labette shale member 26
      - Pawnee limestone member 26
      - Bandera shale member 26
      - Altamont limestone member 27
      - Nowata shale member 27
      - Lenapah limestone member 27
      - La Cygne shale member 28
  - Missouri group 28
    - Kansas City formation 29
      - Hertha limestone member 31
      - Ladore shale member 33
      - Bethany Falls limestone member 33
      - Galesburg shale member 33
      - Winterset limestone member 34
      - Cherryvale shale member 34
      - Drum limestone member 35
      - Chanute shale member 35
      - Iola limestone member 37
    - Lansing formation 37
      - Lane shale member 38
      - Plattsburg limestone member 38
      - Vilas shale member 39
      - Stanton limestone member 39
    - Douglas formation 40
      - Weston shale member 40
      - Iatan limestone member 41
      - Lawrence shale member 41
      - Oread limestone member 41

Pennsylvanian System—*concluded:*
  Shawnee formation
    Kanwaka shale member
    Lecompton limestone member
    Tecumseh shale member
    Deer Creek limestone member
    Calhoun shale member
    Topeka limestone member
    Severy shale member
    Howard limestone member
    Scranton shale member
  Wabaunsee formation
    Burlingame limestone member
    Willard shale member
    Emporia limestone member
    Admire shale member 4
    Americus limestone member 4
    Elmdale shale member 4
    Neva limestone member 4
    Eskridge shale member 4
Permian system 5
  General description 5
    Distribution 5
    Thickness 5
    Lithologic character 5
    Faunal character 5
    Subdivisions 5
  Big Blue group 5
    Council Grove formation 5
      Cottonwood limestone member 5
      Garrison limestone and shale member 5
    Chase formation 5
      Wreford limestone member 5
      Matfield shale member 6
      Florence flint member 6
      Fort Riley member 6
      Doyle shale member 6
      Winfield limestone member 61
    Marion formation 6
      Luta limestone member 62
      Enterprise shale member 6
      Herington limestone member 62
      Pearl shale member 62
    Wellington formation 6
  Cimarron group 64
    Enid formation 67
      Harper sandstone member 68
      Salt Plain shale member 68
      Cedar Hills sandstone member 69
      Flowerpot shale member 69

ermian System—*concluded:*

PAGE
Cave Creek formation.......... 69
  Medicine Lodge gypsum member.......... 70
  Jenkins shale member.......... 70
  Shimer gypsum member.......... 70
Woodward formation.......... 71
  Dog Creek shale member.......... 72
  Whitehorse sandstone member.......... 72
  Day Creek dolomite member.......... 72
Greer formation.......... 73
  Unnamed shale member.......... 73
  Big Basin sandstone member.......... 73
Comanchean system.......... 73
  Cheyenne sandstone.......... 76
  Kiowa shale.......... 76
Cretaceous system.......... 77
  General description.......... 77
    Distribution.......... 77
    Thickness.......... 77
    Lithologic character.......... 78
    Effect on topography.......... 79
    Structure.......... 79
    Faunal character.......... 79
    Subdivisions.......... 81
  Dakota sandstone.......... 83
  Benton formation.......... 83
    Generos shale member.......... 85
    Greenhorn limestone member.......... 85
    Carlile shale member.......... 86
  Niobrara formation.......... 86
    Fort Hays limestone member.......... 86
    Smoky Hill chalk member.......... 87
  Pierre shale.......... 87
Tertiary and later deposits.......... 88
  Ogalalla formation.......... 88
  Quaternary deposits.......... 90
    Glacial deposits.......... 90
    Pleistocene river deposits.......... 92
    Loss.......... 93
    Alluvium.......... 93
    Sand dunes.......... 94

ILLUSTRATIONS.

PLATE.

I. Map showing the geology of Kansas and the adjoining regio
II. Geologic cross section in an east-west direction across the Ka region.
III. Typical fossils of the Cherokee and Marmaton formations.
IV. Typical fossils of the Kansas City formation.
V. Typical fossils of the Lansing, Douglas, Shawnee and Wabau formations.
VI. Typical fossils of the Permian.
VII. Permian limestone and shale in a bluff of Republican river, quarter mile north of Wakefield, Clay county.
VIII. Northern end of Gypsum hills, near Medicine Lodge, Bar county, showing typical bad lands of the Permian red beds.
IX. Typical fossils of the Cretaceous.
X. Dakota sandstone bluffs in eastern Ellsworth county, about miles west of Brookville.
XI. Wall of Dakota sandstone west of Trinidad, Colo. Outcropp edge of sandstone upturned on east slope of Rocky Mount uplift.
XII. The Great Plains of western Kansas.
XIII. Outline map showing distribution of the Quaternary deposits Kansas.
XIV. Map showing location of geological sections A-H, Plates XV-XV
XV. *A*. Section from the state line east of Paola to a point about miles west of Osage City. *B*. Section from the state line e of Fort Scott to Burlington.
XVI. *C*. Section from Kansas City through Olathe and Baldwin alo line of old Santa Fe trail. *D*. Section from Pomona to poi west of Emporia. *E*. Section from Strong City to Halstead.
XVII. *F*. Section from Paxton to Ellinwood. *G*. Section from Spear ville to Mansfield. *H*. Section from Garden City to Medford

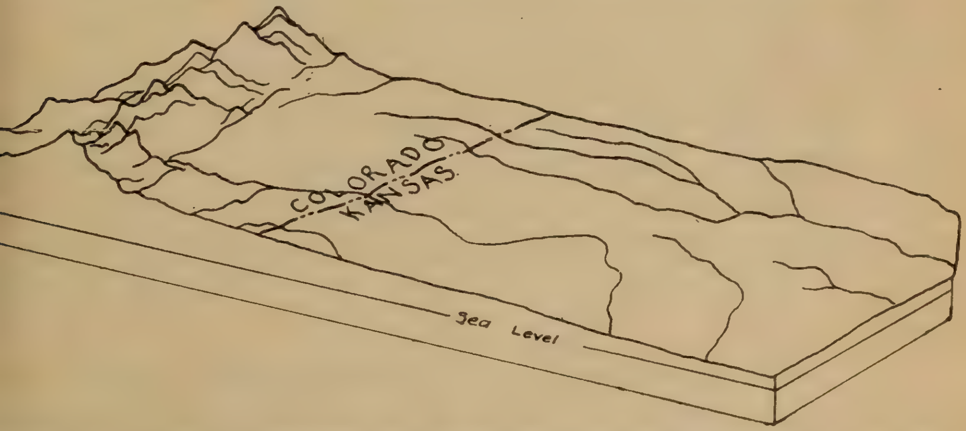
FIGURE.

1. Sketch diagram showing the east sloping plain east of the Rocky Mountains in Kansas and eastern Colorado.
2. Geologic section across Kansas showing the slight sag in the beds in central Kansas.
3. Generalized section of the Des Moines group of the Pennsylvanian in Kansas.
4. Generalized section of the Kansas City, Lansing and Douglas formations of the Missouri group of the Pennsylvanian in Kansas.
5. Section of bluff at Kansas City, showing succession of limestones and shales.
6. Section of rocks exposed near Eudora and Lawrence, Kan.
7. Section showing the succession of rocks in the plateau south of Topeka, Kan.
8. Generalized section of the Shawnee and Wabaunsee formations of the Missouri group of the Pennsylvanian in Kansas.
9. Generalized section of the Big Blue group of the Permian in Kansas.
10. Section across Cottonwood Valley southwest of Elmdale, Kan., showing rock terraces or steps formed by resistant limestone beds and gentle slopes composed of shale.
11. Generalized section of the Cimarron group of the Permian in Kansas.
12. Generalized section of the Comanchean and Cretaceous systems in Kansas.

GEOLOGY OF KANSAS.

INTRODUCTION.

ITS broad features the geology of Kansas is almost ideally simple. The state is a very typical part of the Great Plains ion, which extends from the Dakotas to Texas and from the ky Mountains eastward to the Mississippi, and it has the formly gentle slope and simplicity of geologic structure ich characterize the plains. The surface of Kansas has a eral inclination from west to east, amounting to about ten t per mile, the elevation of the western state boundary being ut 3,500 to 4,000 feet, that of the eastern boundary from to 1,000 feet (fig. 1). The rock formations of which s sloping plan is built lie almost flat, and are exposed in ad north-south bands across the state. In reality they sag htly in central Kansas, the rock slope or dip being toward



IGURE 1.—Sketch diagram showing the east sloping plain east of the Rocky Mountains in Kansas and eastern Colorado.

west in the eastern counties and to the east in the western t of the state. The oldest beds appear at the surface in the t and dip beneath the younger overlying formations which ear in succession as the state is crossed to the west (fig. 2).

ormation of the Rocks of Kansas. The rocks of Kansas, as ssified on the basis of origin, belong to the sedimentary up. Rocks of igneous origin have been found in deep wells, do not come to the surface within the borders of the state.*

A surface exposure of igneous rock has recently been discovered in west central Riley ty, one mile east of Bala. It is a dark-colored basic rock and outcrops only in a very area. (Moore, Raymond C., and Haynes, Winthrop P., Outcrop of basic igneous in north central Kansas, Bull. Am. Assn. Petr. Geol., vol. 4, pt. 2, 1920.)

The formation of the sedimentary rocks may be discuss briefly as an introduction to the summary of the stratigrap of Kansas which follows.

Sedimentary rocks are those composed of the transport fragments or particles of older rocks that have undergone d integration. The chief agencies of transportation are water including rain, streams, lakes and the sea—wind, and glacie Deposition of the rock particles may take place along strean at the bottom of lakes or the sea, where the wind drops its loa or beneath glaciers. Materials such as gravel, sand and cl are carried as solid particles, and after deposition may be co solidated to form conglomerate, sandstone or shale. Other m terials are carried in solution and may be deposited chemicall as in the formation of salt or gypsum, or by the action of plan or animals, as in the formation of limestone or coal. Sed mentary rocks are usually made up of layers or beds, calle strata, which can easily be separated.

By far the most important area of deposition in which sedi mentary rocks are being formed is the bottom of the ocean The bottom of the sea is covered with gravel, sand and mud which are sorted and spread by the waves and currents. A these sediments gather they bury others already deposited When compressed by the weight of overlying materials, and bound together by cement deposited between the grains, the originally unconsolidated sediments are hardened into firm rock.

The oil and gas deposits of the Midcontinent field are confined almost wholly to rocks of the Pennsylvanian system, which outcrop in a broad belt across eastern Kansas and Oklahoma (plate I). In other districts oil and gas in commercial quantities occur in strata of geologic divisions as old as the Cambrian, but they have not yet been found generally in the older rocks of the Midcontinent field.[1] It is known that in a number of localities, chiefly in Oklahoma, there are important oil and gas pools within the Mississippian; and at least from one locality in the Healdton field, possibly also in the Osage, commercially valuable oil has been found in Ordovician rocks. Oil and gas have been found also in the Permian and in the Cretaceous, although it is possible that locally, as in Kansas, the oil and gas in these strata have migrated upward from un-

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[1] Powers, Sidney. Age of oil in southern Oklahoma fields; Am. Inst. Min. Eng., Bull. No. 131, pp. 1971-1982; 1917.

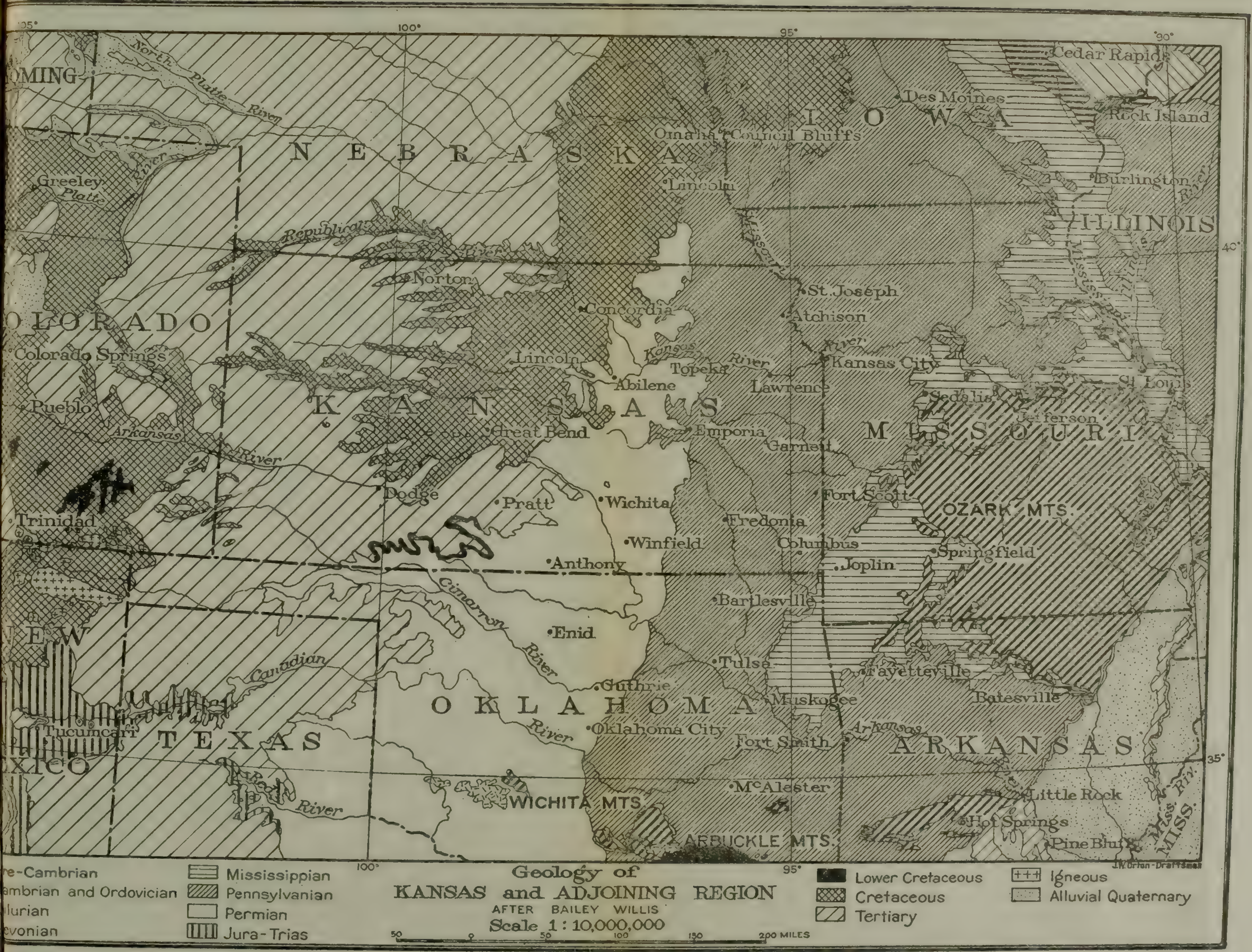

PLATE I.—Map showing the geology of Kansas and the adjoining region.

8-3820

; Pennsylvanian formations. On account of the broader tion of oil and gas which is thus indicated, and because tion for these hydrocarbons is being carried much bee limits of the Pennsylvanian outcrops, it is desirable to r briefly the general stratigraphy and the oil and gas ts of the whole state so far as they are known.

OLDER ROCKS OF THE MIDCONTINENT REGION.

'ambrian. The rocks in the general region of the Midıt field range in geologic age from almost the oldest to the youngest. The oldest rocks are granites and ystalline rocks of probable Archeozoic age which are in the southeastern part of Missouri, in the Arbuckle hita mountains of Oklahoma, in the Rocky Mountains rado, and at points farther distant, north of Kansas. ıe exact age of these isolated patches of very ancient difficult or impossible to determine, it is most convenspeak of them simply as Pre-Cambrian, for in all cases known to be older than the first sedimentary rocks of ozoic. It is known that the Pre-Cambrian rocks extend ıere beneath the later sedimentary formations, since ve been encountered in deep wells at many points out area of their outcrop. Geologic study indicates that ll drilled to a sufficient depth should strike the Prean; that is, that these crystalline rocks represent a nental basement" or floor on which all the succeeding d rocks of the continent are laid down. According ıdant observation in all parts of the world, the Prean marks the lower limit of possible oil and gas deposits. Pre-Cambrian nowhere appears at the surface in Kan drilling in the central part of the state has shown that oaches the surface much more closely than was sup- Sufficient tests have been made to indicate clearly the e of a buried ridge or mountain range of granite which to trend in a direction slightly east of north from east county to the northern limits of the state.[2] No evif metamorphism of the sedimentary rocks immediately ıg the granite has been found, and it is probable that ge represents a part of the Pre-Cambrian floor.

orian and Ordovician. The sedimentary formations rest upon the Pre-Cambrian floor conform essentially

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[2] etailed discussion of this granite is contained in another part of this report.

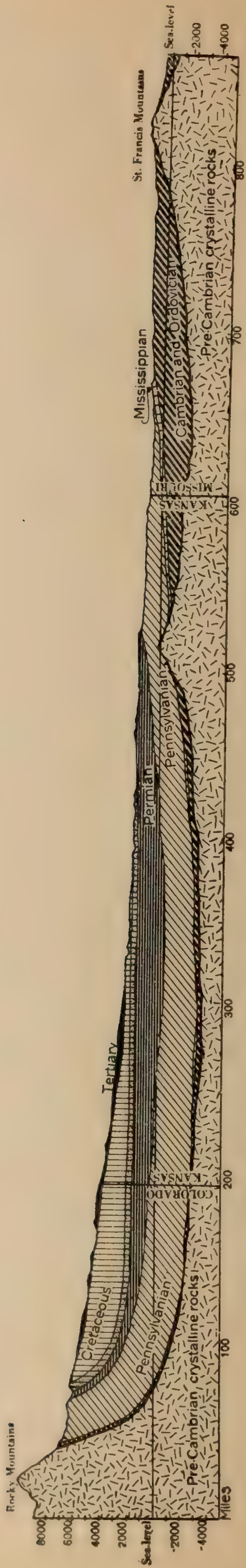

PLATE II.—Geologic cross section in an east-west direction across the Kansas region.

surface. They are nearly horizontal over wide areas
he underlying crystalline rocks have not been deformed,
upturned where the granite has been pushed more or
rply upward by deep-seated mountain-making forces.
here the granites appear at the surface in Missouri,
ma, Colorado or South Dakota, the oldest sedimentary
re upturned around them, the younger formations ap-
, in the order of their age, farther away. (Plate II.)
posure of these lower Paleozoic formations, even at a
e from Kansas, makes possible a more accurate concep-
their character within the state than would be obtained
e record of deep borings alone.

tudied in the Ozark region of Missouri, the rocks be-
he Mississippian and overlying the Pre-Cambrian in-
presentatives of each of the geologic time divisions of
eozoic. The Cambrian and Ordovician systems of this
consisting of dolomites, limestones, shales and sand-
aggregate 2,000 to 2,500 feet in thickness. The suc-
Silurian and Devonian, however, are very thin and ir-
in distribution and are practically confined to the
n, eastern and southern flanks of the Ozark uplift. The
has been recognized in northeastern Oklahoma[3] and
n Arkansas,[4] but beds of this period and of the De-
are wanting throughout most of the region of the Great
[5]

of Kansas, in the upturned strata of the Front Range
Rocky Mountains (plate II), the strata of the Great
are well exposed and may be studied in some detail.
e Cambrian is observed in certain localities, but it has
ness of not more than fifty or sixty feet and for long
es it is absent altogether. The Ordovician, similarly,
ecognized here and there, has a maximum thickness of
0 feet, and disappears north of Denver.

brian and Ordovician strata are present in the Wichita
buckle mountains and surrounding the Black Hills of
Dakota. Since these old formations come to the sur-

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f, J. A., Tahlequah folio, Oklahoma: U. S. Geol. Survey, Geol. Atlas, folio 122,
e Silurian is represented by the St. Clair limestone about 100 feet in thickness.

lliams, H. S.; The Paleozoic Faunas of Northern Arkansas: Ann. Rept., Ark.
ey, 1892, vol. 5, pp. 277-284, 1900.

epard, E. M., Formations in Southwestern Missouri (Geology of Green county,
Mo. Geol. Survey, vol. 12, pp. 65-82, 1892), Northern Arkansas and Oklahoma
ga shale and Sylamore sandstone), referred to the Devonian by various writers,
ly referable to the basal Mississippian.

face at various points on almost all sides of Kansas, it ma supposed that they underlie most of the state, but it shoul noted that their thickness decreases very greatly from eas west, as shown by observations in Missouri and Colora Deep borings in southeastern Kansas indicate the thicknes sedimentary rocks beneath the Mississippian in parts of state to be more than 2,200 feet (Iola),[6] although granite been reported only 1,000 feet below the Mississippian at Pa and Neodesha[8] (?). If the granite of central Kansas alre mentioned is Pre-Cambrian, the older Paleozoic rocks are sent in this region, for the beds which immediately overlie granite are apparently Pennsylvanian in age.

In summary, it appears that a series of dolomite, shale a sandstone formations belonging to the Cambrian and Or vician systems, possibly with thin local deposits of Silurian Devonian age, underlie most of Kansas. These beds are mo than 2,000 feet thick in the eastern part of the state, but pro ably become very much thinner or locally absent to the west.

MISSISSIPPIAN SYSTEM.

Upon the eroded surface of the rocks of the older Paleozo in the Great Plains country is found the Mississippian sy tem, or, as it is called by drillers, the "Mississippi lime." Th Mississippian is a clearly defined, readily traceable strat graphic unit, consisting chiefly of crystalline limestones co taining a rather unusual amount of hard, flinty chert. I Oklahoma and northern Arkansas it includes important beds shale and some sandstone, but where encountered by the drill Kansas and throughout most of Missouri it is essentially a lim stone series. An exception apparently is found locally in ce tral Kansas, according to recent information from well record which indicates a disappearance locally of the limestone and partial replacement by clastic materials. The thickness of th system in the south central part of the Mississippi basin more than 2,000 feet, but in Kansas it is not more than 300 350 feet.

As shown on the accompanying sketch map (plate I), th Mississippian appears at the surface in a band of varyin width almost surrounding the area of older Paleozoic rocks i ark highland. This band of outcrop extends across ri in an east-west direction just north of Missouri river, ings to the south from Sedalia into the Joplin and ield region, where a considerable area in southwest ri, northeastern Oklahoma and northwestern Arkansas ed by Mississippian rocks. The only portion of Kansas h the Mississippian beds occur at the surface is a very area in the southeastern portion of Cherokee county xtreme southeastern corner of the state. The boundary the Mississippian and the succeeding Pennsylvanian the state line from Missouri about fifteen miles north southern border of the state and passes into Oklahoma ine miles from the east Kansas state line.

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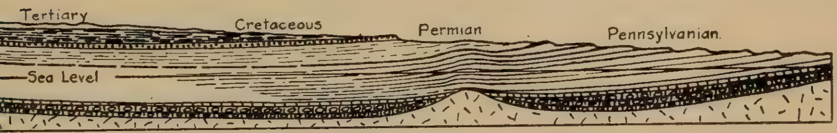
[6] Haworth, Erasmus, and Bennett, John, General Stratigraphy, Special Report on O and Gas: Kan. Univ. Geol. Survey, vol. 9, p. 66½, 1908.

[7] Ibid.

[8] Idem.

rocks of the Mississippian area in Kansas have been d to the Burlington and Keokuk formations, but ac- to recent investigation by the writer there seems little



E 2.—Geologic section across Kansas showing the slight sag in the beds in central Kansas.

ut that this area belongs in the Warsaw division. This ccordance with the determination by Weller[9] of a part Mississippian of the adjoining southwestern Missouri . The subdivisions of the Mississippian have not been ized in other portions of the state, although it seems le that the limestone encountered in deep wells belongs to the Osage group. It is possible that the oil-bearing nes and shales of Chester age in Oklahoma extend north- short distance into Chautauqua county, Kansas, since ear Sedan have reported oil within the "Mississippi Deep wells at various points in Kansas northwest of the sippian outcrops above mentioned have encountered the ne beds of the system. They show that the beds are lly inclined in a west or northwest direction at a rate g from eight to fifteen or twenty feet per mile.

Mississippian has been recognized at points as far west glas (3,110 feet depth), but to what distance farther

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eller, Stuart, personal communication.

west the limestones of this age extend cannot be stated on ev dence at hand. It is apparently absent along most of the li in which the wells have encountered the granite ridge in t east central portion of the state. The Mississippian appears the surface locally where the rocks of the Paleozoic are u turned along the flanks of the Front Range in Colorado.

The upper surface of the Mississippian limestone is ver uneven, having been greatly eroded during pre-Pennsylvani and early Pennsylvanian time. As indicated by well drillin and observations in southeastern Kansas, the top of the Mi sissippian has a variation in elevation of as much as 75 to 9 feet in distances of less than one-half mile. This evidence erosion has been observed throughout the Mississippi basi and has been described by many geologists. It should be noted however, that although there is considerable irregularity i the surface of the Mississippian limestone within a limited di trict, observations over a wider area show a general con formity between the bedding of the Mississippian and that o the overlying Pennsylvanian. This indicates that notwithstanding the widespread and possibly long-continued erosion after the Mississippian, there was no important disturbance o the older beds before Pennsylvanian deposition.

PENNSYLVANIAN SYSTEM.

General Description.

The Pennsylvanian system as observed in Kansas consists o a thick series of alternating shale and limestone formations with irregular beds of sandstone and some beds of coal.

Distribution. Pennsylvania strata appear at the surface i a broad belt extending from northern Iowa to Texas, all o northwestern Missouri, southeastern Nebraska, the eastern one-fourth of Kansas and a large portion of Oklahoma and Arkansas being composed of these rocks (plate I). The Pennsylvanian of the mid-continent region was at one time without doubt continuous with the beds of the same age in Illinois and states farther east, and it is possibly directly continuous with the Pennsylvanian formations which come to the surface in the Front Range of the Rocky Mountains in Colorado. The system is of greatest economic importance because of the oil and gas contained in many of its more porous formations, and because of its deposits of coal, shale, clay and limestone.

ness. The Pennsylvanian rocks of Kansas have a thick- ording to Haworth,[10] of nearly 3,500 feet in the south- of the state and a slightly smaller amount to the total thickness of about 3,000 feet has been measured nsas river. As the Pennsylvanian rocks have a general e west they are consequently much thinner along the order of their outcrop, where only the older forma- e been spared by erosion, and thickest in the counties the belt of Permian outcrop. Since the dip of the ow and the relief of the surface slight, outcrops of formations are separated by a distance of more than from those of the upper. Accordingly, measurement ickness of the lower formations at their outcrop does ate precisely their thickness at points a considerable to the west and compilation of surface measurements show accurately the total thickness of the system. , the record of deep wells indicates that the figures e approximately correct.

gic Character. The Pennsylvanian system is composed ber of varieties of shale, sandstone, limestone, clay which, though rather thin in a vertical direction, are y persistent horizontally. Many of the limestones have ced from the north to the south border of the state me cases a considerable distance into adjoining states. sistence of the Pennsylvanian beds has made the de- dies of Haworth, Bennett, Adams, Beede and others value and wide application, and we now have an general knowledge of the stratigraphy of eastern

a quantitative standpoint, the shales are the most im- f the rocks of the Pennsylvanian, constituting a con- proportion of almost every formation. The shales eneral rather argillaceous. In many cases, however, quite sandy, and at many horizons grade both laterally ically into sandstone. Some of the shales are highly s, in places containing so much lime that they might e called shaly limestones. The general color of the anian shale is gray or yellowish brown, but variegated other colors are not uncommon. Dark or black slaty ith abundant carbonaceous or bituminous matter also

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orth, Erasmus, and Bennett, John, loc. cit., p. 73.

The limestones are probably next in importance in the Pe
sylvanian of the region. They are, for the greater part, li
colored fossiliferous, fine-grained, compact rocks, many of
beds, especially the thicker ones, being also quite cherty. So
are oölitic and thick-bedded. The fragments of fossils of
rious sorts are extremely abundant in many formations, and
certain cases make up almost the entire body of the roc
These include the more or less recognizable fragments
bryozoans, corals, shells of brachiopods and other inver
brates.

Sandstone is abundant at certain horizons, but, quanti
tively considered, it is less important than the foregoing r
types. As a rule, the sandstones are of medium grain and c
tain a great deal of mica. In a few instances they are coar
grained and nonmicaceous. In color they vary from white
blue gray or yellow, but in almost all cases they weather t
yellowish brown. The sandstone formations are not very p
sistent horizontally, grading laterally as well as vertically i
shales of more or less impervious character. The sandsto
have a very great economic importance because of their c
tent of oil and gas at very many places.

Coal is important in the lower divisions of the Pennsylvan
in Kansas, especially in the southeastern portion of the sta
The coal beds of the Cherokee shale and of the overlying Ma
maton formation are the most valuable. Clays are common
certain areas. They occur especially near the base of t
Pennsylvanian associated with beds of coal.

Effect on Topography. The lithologic character and t
structure of the Pennsylvanian rocks of eastern Kansas a
very closely reflected in the topography and physiography
the region. The limestone formations characteristically for
more or less well-defined escarpments with steep eastern slope
and very long, gentle dip slopes to the west, which are traceab
in some instances for miles. The escarpments made by th
outcrops of these resistant formations may be followed wi
the greatest ease from one border of the state to the other, an
have been mapped in some detail by Haworth and Bennett
The outcropping lines of the different formations are show
in the geologic map (plate I). Geologic cross sections draw
in various directions across the state have been prepared wit

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11. Haworth, Erasmus, and Bennett, John, loc. cit. plates VII*b*, VII*c*, 1908.

rable care, [12] a study of which shows the general rela-
the formations to each other and to the surface outcrops
ates XV-XVII).

ture. In common with the Mississippian and other
; outcropping in eastern Kansas and the adjoining re-
ıe Pennsylvanian strata have a gentle inclination out-
om the Ozark highlands. In northeastern Kansas they
ard the northwest, in central eastern Kansas almost
st, and in the southern counties of the state slightly
ɜst. If the Pennsylvanian is continuous beneath the
verlying formations of Permian, Cretaceous and Ter-
ge in the western part of Kansas, the system is a part
hallow sag or syncline which characterizes the broader
e of the state. However, when examined in detail it is
ıt there are many irregularities in the structure of the
vanian rocks. For example, at many points in eastern
the rock strata are absolutely horizontal, or are even
to the east.[13] These irregularities are minor waves
najor structure of the Pennsylvanian, and though not
ɜnt, they are of the very greatest importance to the oil
r, for they control in a very essential way the distribu-
the oil and gas in the rocks. They are the anticlines
for by the geologist.

visions. On the basis of difference in lithologic char-
ıd fossils, and to a certain extent on the evidence of
breaks at places in the series, the rock strata of the
vanian have been divided into a number of formations
nbers. The names used in this report are those which
to accord most closely with the established rules of pri-
the nomenclature of geologic formations, and are, with
v exceptions, the names which have been recommended
ommittee on Geologic Names of the United States Geo-
Survey.[14] A considerable amount of geologic work has
ıe in the region where the Pennsylvanian outcrops, and
livisions which have been recognized have been traced

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worth, Erasmus, Stratigraphy of the Coal Measures of Eastern Kansas: Kan.
Survey, vol. 3, plates I-IV, 1908; Special report on oil and gas; Kan. Univ.
ey, vol. 9, plates VIII-XIII, 1908.

typical anticline may be cited in the vicinity of Alma, Wabaunsee county, in
e is an east dip of 160 feet in six miles. In the Cushing district, the most
of all the Oklahoma pools, there is a vertical distance of only 160 feet from
he dome to the bottom of the adjacent syncline.

nds, Henry, and Greene, F. C., Stratigraphy of the Pennsylvanian series in
Mo. Bur. of Geology and Mines, vol. 13, p. 16, 1915.

across most of the state. They may be accepted, therefore, well-defined stratigraphic units.

DIVISIONS OF THE PENNSYLVANIAN ROCKS OF KANSAS.

Group.	Formation.	Member.
MISSOURI.	Wabaunsee formation.	Eskridge shale. Neva limestone. Elmdale shale. Americus limestone. Admire shale. Emporia limestone. Willard shale. Burlingame limestone.
	Shawnee formation.	Scranton shale. Howard limestone. Severy shale. Topeka limestone. Calhoun shale. Deer Creek limestone. Tecumseh shale. Lecompton limestone. Kanwaka shale.
	Douglas formation.	Oread limestone. Lawrence shale. Iatan limestone. Weston shale.
	Lansing formation.	Stanton limestone. Vilas shale. Plattsburg limestone. Lane shale.
	Kansas City formation.	Iola limestone. Chanute shale. Drum limestone. Cherryvale shale. Winterset limestone. Galesburg shale. Bethany Falls limestone. Ladore shale. Hertha limestone.
DES MOINES.	Marmaton formation.	La Cygne shale. Lenapah limestone. Nowata shale. Altamont limestone. Bandera shale. Pawnee limestone. Labette shale. Fort Scott limestone.
	Cherokee shale.	Undifferentiated.

In the development of our present knowledge of Pennsylvanian stratigraphy in Kansas, these beds have been subdivide into various groups and formations which do not accord wit present classification. Many geologic names have been used and a good deal of confusion has followed the different definitions and use of geologic names by various workers. The development of the stratigraphic classification adopted in thi report, and its relation to the names which have previousl sed, is shown in detail in a previous publication.[15] Ref- to this summary of classification will obviate the neces- recounting the usage of various authors in the definition scription of the stratigraphic units.

general stratigraphy of the subdivisions of the Pennsyl- will be discussed briefly. The descriptions must, how- e regarded as a mere summary of Kansas geology, d to the use of those especially interested in the develop- f oil and gas. The discussion of stratigraphic problems ely scientific interest, and matters not germane to the : of this report, are purposely omitted.

DES MOINES GROUP.[16]

Pennsylvanian system of the western Mississippi valley en divided into two main groups, the lower termed the oines group and the upper the Missouri group. These ns, which are identical with the "Lower" and "Upper easures," respectively, of earlier geologists, were origi- ade in the belief that the higher, younger portion of the lvanian was differentiated from the lower part by a reater proportion of calcareous matter. This is in truth rally distinguishing feature, but detailed studies over a rea have shown that limestones are more abundant in s Moines group than first supposed, and that shale and ne are almost if not quite as important in the Missouri as in the Des Moines. Lithologic differences are there- t so sharply defined. However, a well-marked faunal occurs at the line of division between the two groups, Missouri there is evidence of an erosion break of wide at about the same horizon. The major classification of nsylvanian indicated may be accepted, therefore, in this It is to be hoped that additional paleontologic study ke possible a subdivision of the Pennsylvanian of the Mississippi basin into groups which are at least ap- ately correlative with those defined in the Appalachian

Des Moines group includes approximately 500 to 800 feet lower strata of the Pennsylvanian of Kansas. It con- hiefly of clastic materials such as shale and sand-

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oore, Raymond C., and Haynes, Winthrop P.; Oil and Gas Resources of Kansas: Survey, Bull. 3, 1918.

eyes, C. R.; The Geological Formations of Iowa: Iowa Geol. Survey, vol. 1, pp. 93. Named from Des Moines, Iowa.

stone, but contains an important minor content of limes (fig. 3). Deposits of coal and clay of great economic v also occur. The porous sandstones of the Des Moines are chief containers of the oil and gas deposits of Kansas and O homa.

Rocks of the Des Moines group outcrop in an irregular b surrounding the older beds. They occupy the southeast portion of Kansas, extending from Miami county on the no east to Montgomery county on the southwest, including al portions of Linn, Bourbon, Crawford, Neosho, Cherokee Labette counties. The beds of the Des Moines dip to the w and northwest and are continued from the zone of their c crop an unknown distance. It appears from a study of v records in Butler county and adjacent counties that the Moines group extends at least at far west as this part of state, but it is thinner than at the outcrop.

Variations in the thickness of the Des Moines group largely dependent upon changes in the character of the Che kee shale. The total thickness of the group may be obtained measuring its various units in the area of their outcrop. Th may be supplemented by the records of deep wells, and indic a varying thickness in different localities: at Atchison, feet; Kansas City, 669 feet, etc.

The Des Moines group has been divided into two formati of approximately equal thickness, the Cherokee shale below a the Marmaton formation above. This appears to be very sirable both on lithologic and faunal grounds. The Cherok is essentially a shale and sandstone formation, almost lacki in limestone; but beginning with the persistent limestone the Fort Scott horizon, the Marmaton contains a number well-defined limestone members. Distinct differences in t faunas of the two formations have been recognized by Bee and Rogers.[17]

Cherokee Shale.[18]

The Cherokee shale, at the base of the Pennsylvanian sy tem in Kansas, is especially important because it contains t more or less irregular beds of sandstone which are the chi oil and gas producers of the state (fig. 3). The formation

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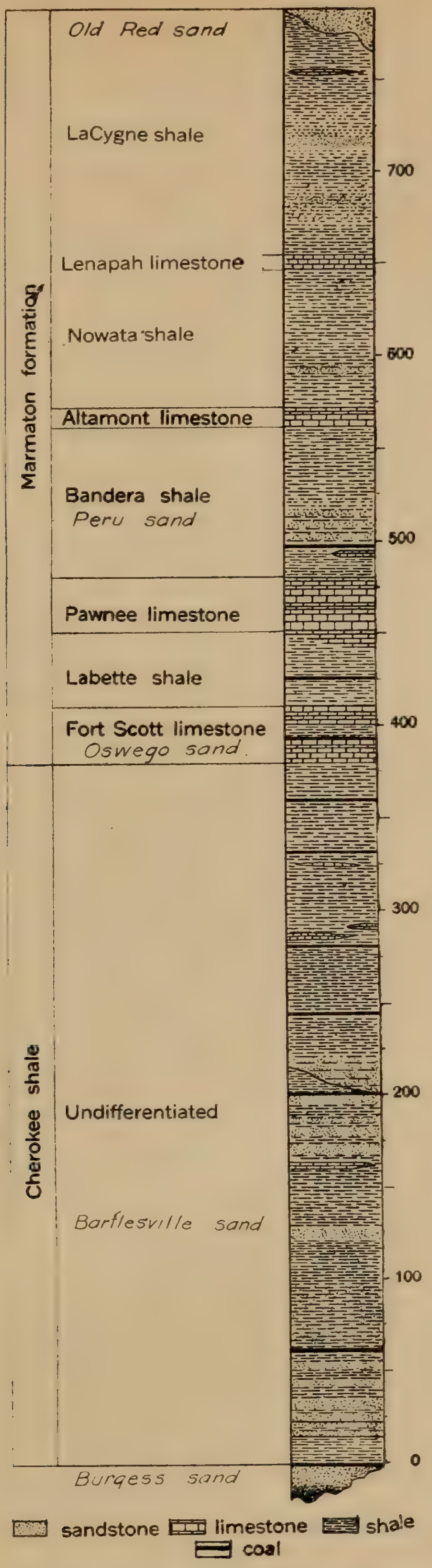
[17] Beede, J. W. and Robert, A. F.; Coal Measures Faunal Studies: Kan. Un Geol. Survey, vol. 9, pp. 318-385, 1908.

[18] Haworth, Erasmus, and Kirk, M. Z.; The Neosho River Section: Kan. Un Geol. Survey, vol. 2, p. 105, 1894. Named from Cherokee county, Kansas.



IGURE 3.—Generalized section of the Des Moines group of the Pennsylvanian in Kansas.

exposed at the surface over most of Cherokee county, fr which it takes its name, and in the eastern portions of Cra ford and Bourbon counties. The belt of Cherokee exten northeastward across most of Missouri and has been trac southwest through Oklahoma as far as Arkansas river. It possible that it extends eastward into Arkansas.

The Cherokee shale has an average thickness of 400 to 5 feet in southeastern Kansas, but there is considerable vari tion. At Topeka deep drilling indicates a thickness of 7 feet, at Atchison 598 feet, at Emporia 351 feet. It appea from this that the Cherokee shale is thicker to the north a northwest, but not so thick to the west. In Oklahoma t Cherokee shale is very much thicker, aggregating more tha 1,000 feet in the vicinity of Pryor creek,[19] and if correlat with the Winslow and Boggy formations farther south, a tot thickness of more than 1,500 feet is attained. The lower pa of the Pennsylvanian in eastern Oklahoma is certainly old than the Cherokee shale in Kansas.

The lithologic character of the Cherokee shale is indicat in the generalized section (fig. 3), which shows a succession shales and sandstones, with beds of coal and discontinuo limestone layers at certain horizons. Shale constitutes by fa the greatest part of the formation, although the proportion sandstone is not negligible in quantity. There is considerabl lithologic variation, both vertically and laterally, in the Cherokee shale. The color ranges from light ash gray to yellowis brown and jet black, and there are changes in the materia from finest-grained clay shale to very sandy shale and sandstone. Sandstone beds are very abundant throughout th Cherokee, but are not of sufficient persistency to be of value i stratigraphic study. They are the source of most of the production of southeastern Kansas and the adjacent portion o Oklahoma, and possibly also in the Butler county field. Th Bartlesville sand is the most important of the oil and gas horizons of the Cherokee. It has been encountered throughou most of the producing field. At the base of the formation i many places is the Burgess sand. Other oil and gas sands o the Cherokee are recognized in the description of individua districts which follow.

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[19] Shannon, C. W. and Trout, L. E.; Petroleum and Natural Gas in Oklahoma Okla. Geol. Survey, Bull. 19, pt. 1, p. 84, 1915.

The Cherokee shale is not as abundantly fossiliferous as ne of the divisions of the Kansas Pennsylvanian, but it is rly well defined faunally. The most abundant and charac-istic fossil is the small productid *Marginifera muricata* ee plate III). The little shells of *Chonetes mesolobus,* which characterized by the sharply defined double furrow on the ıvex valve, is also very common. It occurs also in the Mar-ıton formation but is not known to be present above this rizon. The remainder of the fauna consists of large cephalo-ds and other mollusks, a few corals and bryozoans, and some ıg-ranging brachiopods.

Marmaton Formation.[20]

The Marmaton formation, in striking contrast to the under-ng Cherokee shale, contains a number of well-defined mem-rs which have been traced the entire length of the forma-n outcrop across the state. Between the limestones are rsistent shale members. Although differentiated almost en-ely on a physiographic basis,[21] the Marmaton formation is a tural lithologic unit and has a fauna which is sharply dis-ıct, both from that of the underlying Cherokee and from at of the beds of the succeeding Missouri group. Since no eak in sedimentation or marked change in lithologic char-ter occurs within the formation as here defined, and since the ssils of the Marmaton are a unit, there seems to be little no basis, so far as Kansas is concerned at least, for dividing e Marmaton into two formations as has been done in Mis-uri.[22]

The outcrop of the Marmaton formation appears as a broad ınd twenty to thirty miles wide, trending in a direction from ɔrtheast to southwest across southeastern Kansas. It is the ost important surface formation in Labette, Crawford and ourbon counties. In this district the Cherokee is buried a latively slight depth, so that drilling operations are inex-ensive.

The average thickness of the Marmaton is about 300 feet to

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[20] Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol. ırvey, vol. 3, pp. 92, 94, 1908. Named from Marmaton river, eastern Kansas.

[21] Haworth, Erasmus, and Bennett, John; General Stratigraphy, Special report on l and gas: Kan. Univ. Geol. Survey, vol. 9, pp. 74-75, 1908.

[22] Hinds, Henry, and Greene, F. C., loc. sit., The formations in the Missouri report rresponding to the Marmaton formation are the Henrietta formation below, and the leasanton formation above.

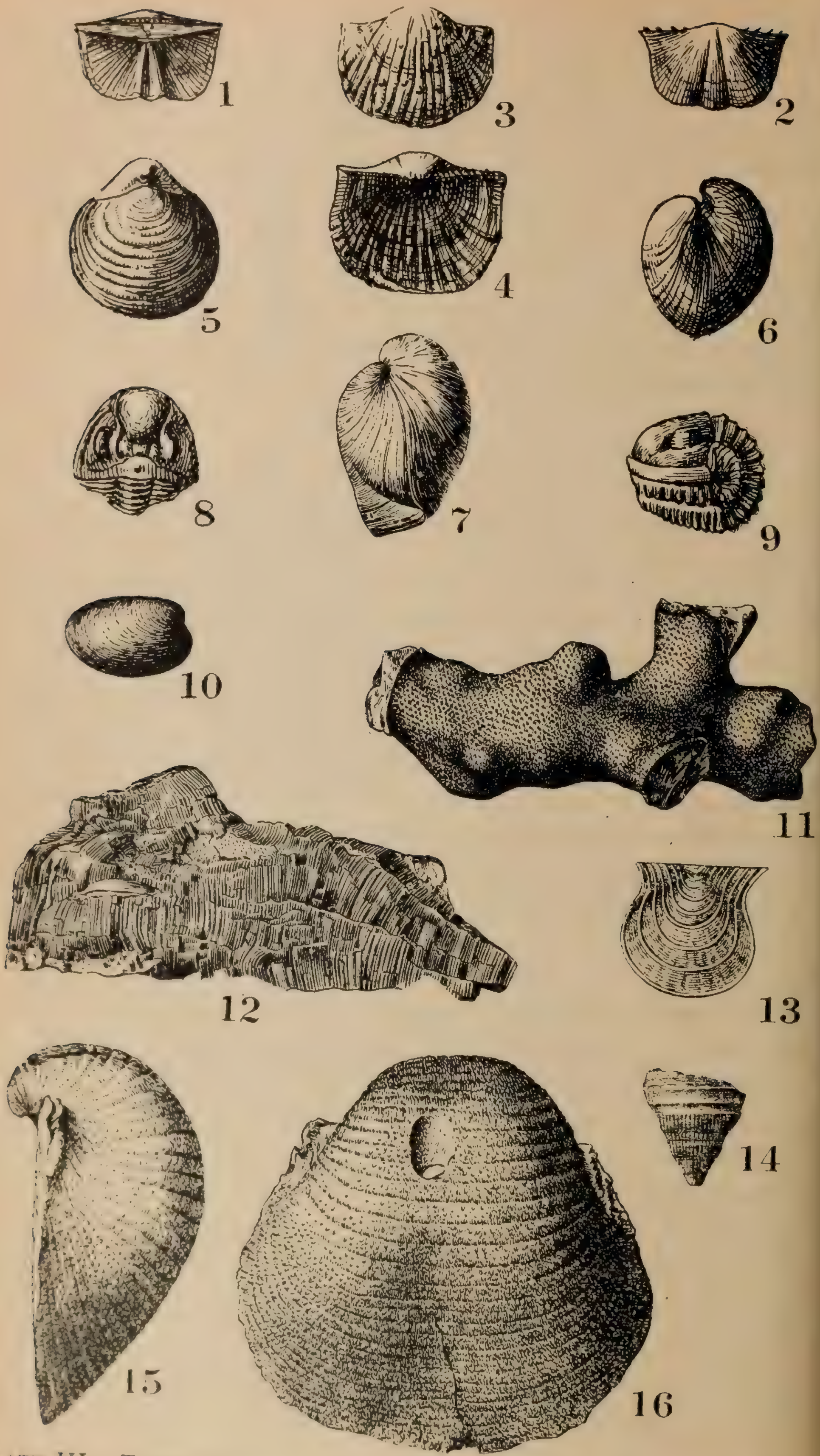

Plate III.—Typical fossils of the Cherokee and Marmaton formations.

feet. The entire thickness is present, of course, only
rd the west border of the belt outcrop, where the upper
bers of the formation have not been removed by erosion.

e Marmaton is characterized by an abundance of inverte-
fossils, at least sixty new species being introduced at the
base of the formation. On account of its extraordinary
dance in some of the limestones of the Marmaton and its
ve absence from the higher beds of the Pennsylvanian in
as, the coral *Chaetetes milleporaceus* (plate III) may be
rded as one of the most striking paleontologic features of
ormation. This species which is marked by the almost
oscopic size of the individual corallites forms colonial
ths of remarkable size, some of them three or four feet in
eter. Other common fossils in the Marmaton are *Squa-*
ria perplexa, Marginifera muricata, Axophyllum rude,
lipora nodulifera, and *Griffithides scitula.*

e Marmaton formation includes eight members of alter-
g limestone and shale.

rt Scott limestone member.[23] At the base of the Mar-
n is the Fort Scott limestone, comprising a lower lime-
bed, 5 to 18 feet thick, a thin but persistent intermediate
bed 7 to 8 feet thick, and an upper limestone bed 10 to
et thick. The total average thickness of the member is
about 30 feet. The Fort Scott limestone appears at the
ce in a narrow band at the east edge of the Marmaton
of outcrop, and extends from the south border of the
near Chetopa and Oswego to the east state boundary in
icinity of Fort Scott. It forms a prominent escarpment
t the entire distance. In places the top of the limestone
rked by a long dip slope which extends miles to the west.
s been determined that[24] the Wheeler sand in the Cushing

LANATION OF PLATE III. Corals: *Chœtetes milleporaceus,* part of a colonial
broken to show the slender, closely packed corallites, (12); *Axophyllum rude,* a
traight horn coral, viewed from the side, (14). Bryozoans: *Fistulipora nodulifera,*
ve growth composed of very minute cells which open outward in tiny apertures
Brachiopods: *Chonetes mesolobus,* a small concavo-convex shell the middle por-
which is marked off in a small, distinct lobe, (1) view of concave brachial valve,
w of convex ventral valve; *Marginifera muricata,* a shell of the Productus type
ther coarse ribs and small spines, (3) *Squamularia perplexa,* a rounded shell with
ent beaks, the surface marked by fine radiating spines and concentric growth lines,
achial view, (6) side view; *Composita subtilita,* one of the commonest Pennsyl-
fossils, side view, (7); *Pustula punctata,* a large Productus type shell with very
us small spines arranged in distinct concentric bands, (15) side view showing
ty of ventral valve, (16) ventral view. Pelecypods: *Nuculopsis ventricosa,* small,
shelled, with very convex valves, (10); *Aviculopecten interlineatus,* a small scallop
ominent concentric ridges (13). Trilobites: *Griffithides scitulus,* a rolled up speci-
) showing head shield, (9) side view.

Swallow, G. C.; Preliminary Report of the Geol. Survey of Kansas, p. 25, 1866.
for Fort Scott, Bourbon county, Kansas.

Shannon, C. W. and Trout, L. E.; loc. cit., p. 86.

district, the Oswego sand in the Bartlesville pool, and possibl certain sands in the Glenn pool, are at the horizon of the Fo Scott limestone member.

Labette shale member.[25] The Labette shale lies between th Fort Scott limestone and the succeeding Pawnee limestone, it thickness ranging from 20 to 60 feet in Kansas and to mor than 120 feet in northern Oklahoma. The formation consists o clayey and sandy shales, which grade locally into somewha shaly sandstone.

Pawnee limestone member.[26] The Pawnee limestone is massive, rather fine-grained limestone having an average thickness of about 45 feet where completely developed. A maximu thickness of 52 feet has been observed in Kansas.[27] It is exposed in a narrow zone from a point west of Chetopa to th east Kansas border in the vicinity of Fulton. The Pawne limestone may be distinguished readily from the underlyin Fort Scott limestone by its massive bedding and its large content of iron. The Pawnee limestone is distinctly less fossiliferous than the Fort Scott.

Bandera shale member.[28] The Bandera shale is a rathe thick, somewhat lenticular member, blue to black in color. I measures from 60 to 120 feet in Kansas, but according to observations in northern Oklahoma it is much thinner there Near Oolagah the Bandera disappears and the Pawnee and Altamont limestones come together, forming the Oolagah limestone of Oklahoma geologists, or the "big lime" of drillers The Bandera shale outcrops in a zone three to eight miles in width, which reaches from the south part of the state in the vicinity of Altamont northeastward to the vicinity of Prescott As a whole the shale is rather argillaceous, but there are gradations to sandy shale, shaly sandstone or pure sandstone Quarries for flagstone are operated at various points along the outcrop. Some of the oil and gas sands of Kansas are at this horizon, and the Peru sands of the Dewey-Bartlesville field in Oklahoma have been referred to this member.[29] Coal is locall important in the Bandera shales, being mined near Hammond

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[25] Haworth, E.; loc. cit. Named from Labette county, Kansas.

[26] Swallow, G. C.; loc. cit., p. 9.

[27] Haworth, E., and Bennett, John; loc. cit., pp. 83-84.

[28] Adams, Geo. I.; Stratigraphy and Paleontology of the Upper Carboniferou Rocks of the Kansas Section: U. S. Geol. Survey, Bull. 211, p. 32, 1903. Named fro Bandera, Bourbon county, Kansas.

[29] Shannon, C. W., and Trout, L. E.; loc. cit.

amont limestone member.[30] The Altamont limestone is a well-defined horizon extending from the western counties issouri across Kansas and a considerable distance into oma. According to Haworth and Bennett[31] it has a maxi- thickness of 10 feet, decreasing in places to no more than feet. In northern Oklahoma it is described as having erage thickness of about 30 feet.[32] The Altamont lime- is a rather hard, massive, highly siliceous limestone, o bluish gray in color. It is especially characterized by oundance of the fossil *Squamularia perplexa*. The Alta- forms a prominent escarpment throughout the greater of its outcrop.

vata shale member. Above the Altamont limestone is a persistent shale member which outcrops in a narrow from Pleasanton southward to Parsons and Edna and into oma. It appears that the correct name for this member Nowata shale from the name given by Ohern[33] in Okla- The name Walnut shale given by Haworth and Ben- is not available for this division, as it had previously employed to designate a formation in the Cretaceous of . The average thickness of the shale is about 70 feet. vidth of the outcrop zone varies from one mile to six or miles. The physical properties of the Nowata shale are ially the same as those of associated shale members. iction of oil or gas is not reported from this horizon.

apah limestone member.[35] A thin but persistent lime- bed which has been called the Lenapah member, succeeds owata shale. It has an average thickness of 8 to 10 feet nsas and is prominently exposed on both sides of Verdi- iver at the south line of the state at Coffeyville. Accord- Haworth and Bennett,[36] it occupies a zone 7 to 8 miles along Pumpkin creek and its tributaries in northeast te county. To the north it is much thinner. The name ville limestone is inapplicable to this horizon inasmuch

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Adams, Geo. I.; A Geologic Section from Galena to Wellington: Kan. Univ. Geol. vol. 1, p. 22, 1896. Named from Altamont, Labette county, Kansas.

Haworth, Erasmus, and Bennett, John; loc. cit., p. 85.

Shannon, C. W., and Trout, L. E.; loc. cit. p. 87.

Ohern, D. W.; The Stratigraphy of the Older Pennsylvanian Rocks of Northeast ahoma: Univ. of Okla., Bull. 4, p. 23, 1910.

Haworth, E., and Bennett, John; idem, p. 86.

Ohern, loc. cit., p. 25.

Haworth, E., and Bennett, John; idem, p. 87.

as the name had earlier been used for a very different stratigraphic division.

La Cygne shale member. A thick, persistent member at the top of the Marmaton formation, consisting of a variety of shales and intercalated sandstones, with some thin, discontinuous beds of limestone is here termed the La Cygne shale. The average thickness of the shale is about 125 feet, but in the vicinity of Blue Mound, Boicourt and La Cygne a thickness of 150 feet has been observed. The La Cygne shales are valuable on account of their content of heavy beds of sandstone and limestone at different places. The oil-producing sands of the Rantoul, Paola and other districts in eastern Kansas belong in part at least to this horizon. The name Pleasanton shale, which has previously been used for this member in Kansas reports, is not correctly applied. This name was given to a larger division. The new term here employed is taken from the town of La Cygne in Linn county.

MISSOURI GROUP.[37]

The Missouri group, comprising the upper or barren portion of the "Coal Measures," resembles the upper half of the Des Moines group lithologically, but differs from that group as a whole in the greater persistency of its individual members and in containing more limestone, less sandstone, and much less coal. It is sharply distinguished from the Des Moines by faunal characters and at least in certain areas is limited below by an unconformity. From an economic standpoint the Missouri group is much less important than that underlying it, since it contains but little coal, or, so far as known, oil or gas.

The formations of Missouri age comprise much the larger portion of the Pennsylvanian in Kansas. Their outcrops form a broad band in a north-south direction across the state immediately west of the Des Moines beds. The west boundary of the group is an irregular line trending almost due south from Marshall county to Cowley county.

The total estimated thickness of the Missouri group in central Kansas, based on observations of the surface outcrops, is more than 2,000 feet. However, the formations become somewhat thinner toward the northwest and west, as indicated by p drilling. The Missouri group in southeastern Kansas a thickness of approximately 1,500 feet.

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[37] Keyes, C. R.; The Geological Formation of Iowa: Iowa Geol. Survey, vol. 1, p. 85, 1893. Named from northwestern Missouri.

The lithologic character of the Missouri group is indicated the generalized columnar sections, figures 4 and 5. Here, well as in the lower part of the Pennsylvanian in Kansas, le is quantitatively much the most important rock type, limestone forms a very essential and prominent part of group because of the persistency of the limestone mems and their pronounced effect on topography. In the lower tion of the Missouri group limestone comprises approxitely one-half the section. Sandstones are locally very thick l massive, but in general their lateral extent is not great.

n the basis of lithologic character and the contained fos, the Missouri group has been divided into five formations. ese, in their order from bottom to top, have been given following names: Kansas City, Lansing, Douglas, Shaw, Wabaunsee. Each of these formations will be described efly.

Kansas City Formation.[38]

t the base of the Missouri group is the Kansas City fortion, which may be differentiated readily as a lithologic and nal unit from other parts of the Pennsylvanian system in nsas. Its outcrop forms a somewhat irregular but clearly ined belt trending slightly west of south from the vicinity Kansas City to Montgomery county. It has been traced also onsiderable distance beyond the borders of the state into ssouri and Oklahoma. The total thickness of the Kansas y formation varies from 200 to more than 300 feet, the ckness at Kansas City being about 225 feet (see fig. 4). observed at its type locality, more than half of the forman consists of limestone, contrasting sharply with most of associated formations. Shale members of the Kansas City argillaceous or calcareous, but in some cases are black and ty. There is very little sandstone in the formation, alough thin beds occur locally. The Kansas City formation one of the best-defined stratigraphic horizons in the eastn part of Kansas. As indicated in the table of formations, ne members of alternating limestone and shale are included the Kansas City formation.

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38. Hinds, Henry, and Greene, F. C.; loc. cit., p. 23. Named from Kansas City, Mo.

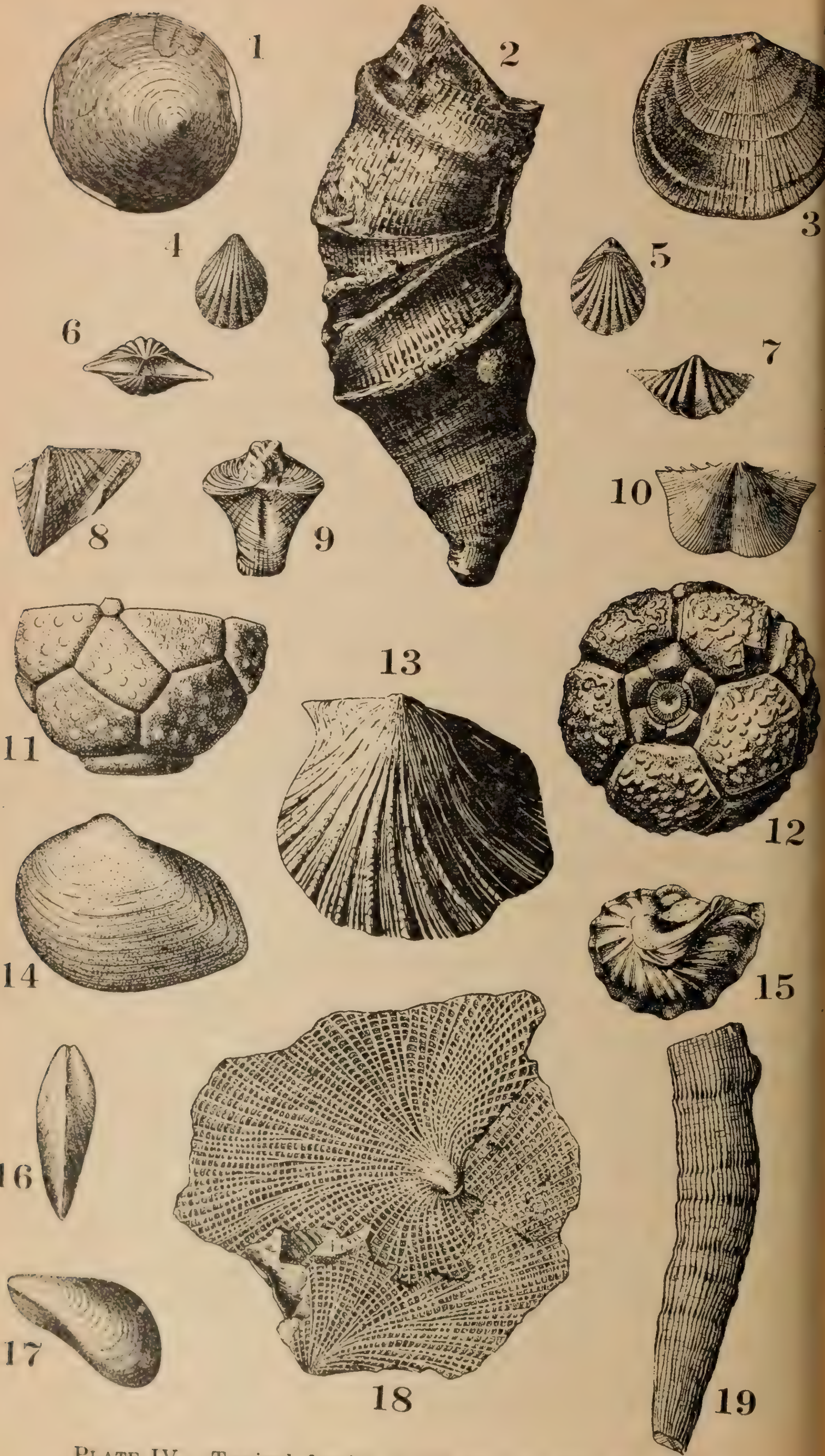

Plate IV.—Typical fossils of the Kansas City formation.

om the standpoint of the fossils which are contained in
Kansas City formation there appear to be three subdi-
ns, the first including the beds below the Drum limestone,
econd composed of the Drum, and the third including the
bers above the Drum limestone. The lower part of the
as City formation is chiefly distinguished faunally from
ubjacent Marmaton beds by the appearance of a consider-
number of new species which become common. Among
may be mentioned *Chonetes verneuilianus, Spiriferina*
ickiensis, Conocardium parrishi, Schizodus wheeleri,
kidonotus percarinatus and *Lophophyllum distortum*
plate IV). The Drum limestone, which is more or less
c, contains a fauna which is very different from those of
parts of the Pennsylvanian in Kansas. It is dominantly
osed of mollusks which occur both in great variety and
ordinary numbers. Among the most common and in-
ting of these are representatives of the genus *Pseudomo-*
, which is commonly an element only of the Permian
as. The upper part of the Kansas City formation con-
a very interesting crinoid fauna, which has been studied
ially in the vicinity of Kansas City. The large coral
oophyllum torquium and many of the common brachio-
of the Pennsylvanian are numerically very abundant in
part of the formation.

rtha limestone member.[39] The Hertha limestone, erro-
sly called Bethany Falls limestone in earlier Kansas re-
,[40] is a resistant, heavy-bedded, gray, crystalline lime-
, varying in thickness from a maximum of 22 feet, meas-

PLANATION OF PLATE IV. Corals: *Lophophyllum distortum,* a slender, straight horn
ith thin walls and a small central axis or pseudocolumella, 19; *Campophyllum tor-*
a robust coral which in some instances grows more than a foot in length, ex-
abundant in some Kansas limestones, 2. Crinoids: *Cromyocrinus kansasensis,* 11;
ycrinus verrucosus, 12, calyces of robust species. Bryozoans: *Septopora biserialis,*
the lace pattern type, 18. Brachiopods: *Orbiculoidea convexa,* a primitive but un-
large round shell with a conical point, 1; *Derbya crassa,* a flat shell with radiat-
s which is very common in some beds, 3; *Hustedia mormoni,* a small form with
ribs and prominent beaks, 4 ventral valve, 5 dorsal valve; *Spiriferina kentucki-*
distinguished by its coarse ribs, fine concentric surface lines and shape, view of
ine 6, ventral valve 7; *Chonetes verneuilianus,* marked by a deep, angular depres-
the ventral valve, 10. Pelecypods: *Pseudomonotis hawni,* a somewhat irregular
ith ribs of unequal size, 13; *Schizodus wheeleri,* nearly smooth but with a prominent
xtending from the beak, 14; *Myalina swallovi,* a small, very oblique shell with the
at the sharp point, 16 view along hinge line, 17 side view. Gastropods: *Pharki-*
s percarinatus, a roughly knobbed shell coiled in a single plane, side view 15.

Adams, G. I.; Stratigraphy and Paleontology of the Upper Carboniferous Rocks
Kansas Section: U. S. Geol. Survey, Bull. 211, p. 35, 1903. Named from Hertha,
county, Kansas.

Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol.
, vol. 3, pp. 45-46, and 100-103, 1898. Also, Haworth, Erasmus, and Bennett,
General Stratigraphy, special report on oil and gas: Kan. Univ. Geol. Survey,
pp. 89-91, 1908.

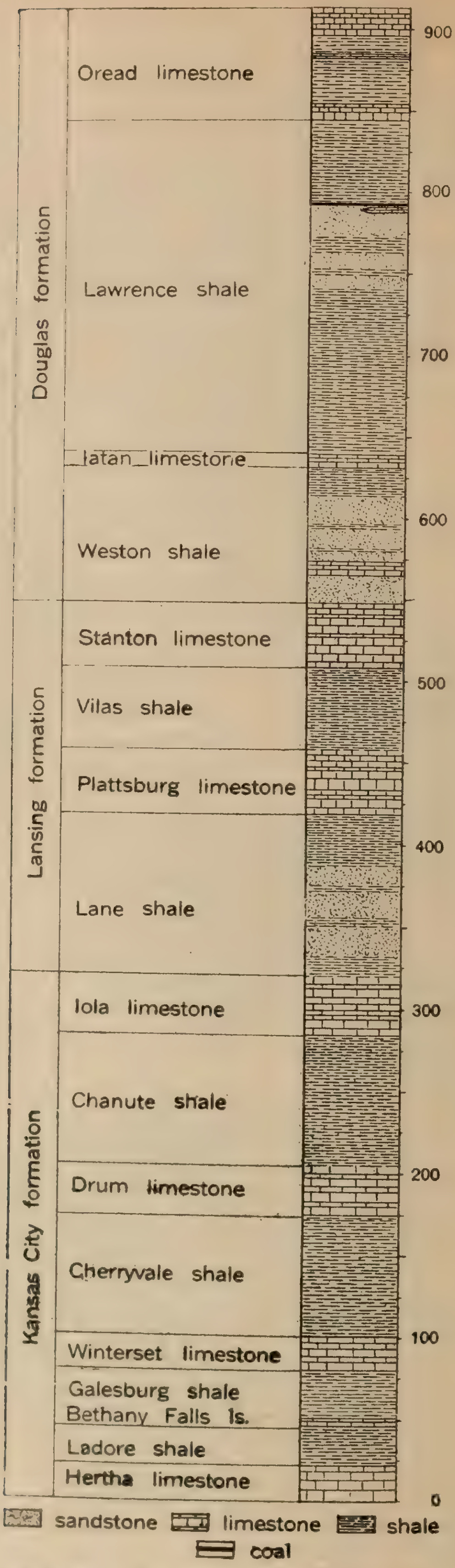

FIGURE 4.—Generalized section of the Kansas City, Lansing and Douglas formations of the Missouri group of the Pennsylvanian in Kansas.

at Uniontown,[41] to nothing where it disappears to the h in the vicinity of Mound Valley. In Missouri the Hertha stone has a thickness ranging from 4 to 18 feet.[42] In places the limestone is quite ferruginous but elsewhere eaches to a nearly pure white. Because of its resistence osion it forms a well-marked escarpment above the soft ygne shale of the Marmaton formation.

dore shale member.[43] The Ladore shale is a clayey or y shale which grades locally into shale, limestone or sand-. It immediately overlies the Hertha limestone and aps at the surface to the west of the Hertha escarpment. The ness of the Ladore ranges from less than 3 feet near sas City to a maximum of more than 40 feet near the ern border of the state. Towards the extreme south e the Hertha limestone is absent the Ladore shale rests tly upon the La Cygne.

thany Falls limestone member.[44] Overlying the Ladore is the persistent Bethany Falls limestone, which has been d from the southern part of Kansas across Missouri and Iowa. As observed in the north part of its outcrop, this ber consists of two main beds—the lower, a thick, mas- somewhat loosely cemented, unfossiliferous limestone, h locally has a somewhat oölitic texture; and the upper, a r thin-bedded, fossiliferous limestone. The formation is or dark gray in color. Its thickness is about 22 or 23 feet ansas City, but farther south it is gradually smaller, until e vicinity of Mound Valley it is less than 4 feet, and far- south it disappears.

lesburg shale member.[45] The Galesburg shale, overlying Bethany Falls limestone, is a clay shale formation which ges locally to sandy or bituminous shale. The thickness of nember ranges from 5 to 6 feet, as observed in the vicinity ansas City, to 60 feet in northwestern Labette county.

Haworth, Erasmus, and Bennett, John; loc. cit., p. 90.

Hinds, Henry, and Green, F. C.; loc. cit., p. 116.

Adams, G. I.; Economic Geology of the Iola Quadrangle, Kansas: U. S. Geol. Bull. 238, pl. 1, 1914. Named from Ladore, Neosho county, Kansas.

Broadhead, G. C.; Coal Measures in Missouri: St. Louis Acad. Sci., Trans., vol. 20, 1868. Named from Bethany Falls, Harrison county, Missouri. This member n called Mound Valley limestone in earlier Kansas reports.

Adams, G. I.; loc. cit., p. 18. Named from Galesburg, Neosho county, Kansas.

Winterset limestone member.[46] This member is a blue, thi bedded limestone with buff shaly partings. Locally it is di tinctly cross-bedded, and in its upper portion is characterize by an abundance of chert. The large amount of chert is pe haps the most prominent feature of the member, distinguishin it from other limestones of the formation. The main che beds at Kansas City belong to the Winterset member. In t southern portion of the Winterset outcrop in Kansas the che is so abundant that the cherty debris from the weathering the member covers considerable areas. The chert is da blue or nearly black and contains an abundant mollusca fauna. The thickness of the Winterset is nearly 30 feet Kansas City and farther to the northwest in Missouri it reach a maximum of 40 feet. Toward the southwest in Kansas, ho ever, the formation becomes thinner, decreasing to less than or 6 feet in the vicinity of Cherryvale. The member forms prominent escarpment between Erie and Shaw.

Cherryvale shale member.[47] Above the Winterset limesto is a rather thick argillaceous or calcareous shale, called t

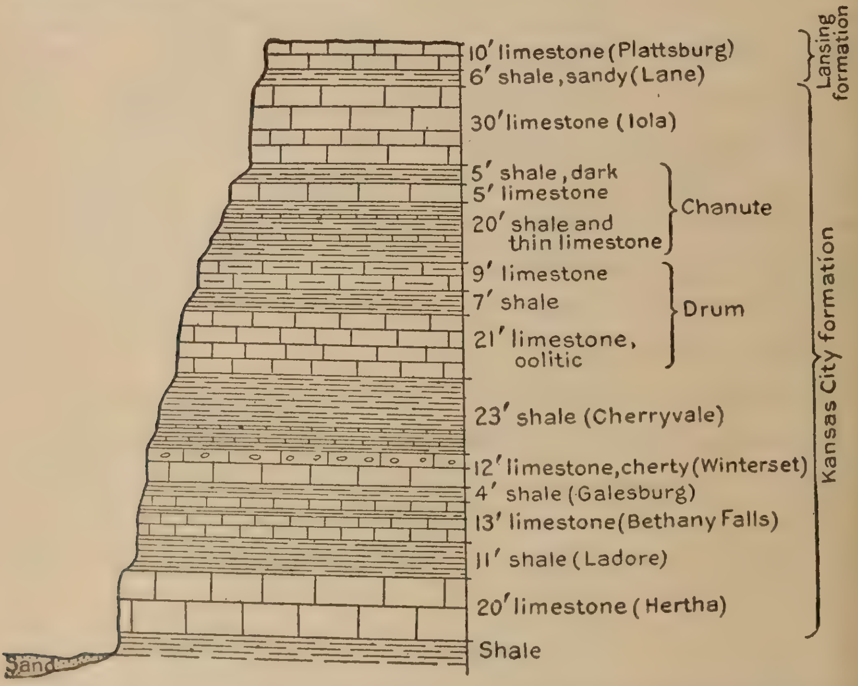

FIGURE 5.—Section of bluff at Kansas City, showing succession of limestones and shales. (U. S. Geol. Survey.)

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[46] Tilton, J. L., and Bain, H. F.; Geology of Madison county: Iowa Geol. Surv vol. 7, pp. 517-519, 1897. Named from Winterset, Madison county, Iowa. This mem was called Dennis limestone in an earlier report (Haworth, Erasmus, and Bennett, Jo Special report on oil and gas: Kan. Univ. Geol. Survey, vol. 9, p. 93, 1908).

[47] Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. Ge Survey, vol. 3, p. 483, 1896. Named from Cherryvale, Montgomery county, Kansas.

rryvale shale. Locally, as in the vicinity of Coffeyville, the
rryvale shale is very sandy, but at Cherryvale it is a good
shale and is extensively used in the manufacture of brick.
n lenticular limestones occur in the shale toward the north.
maximum thickness of the Cherryvale, as recorded in the
nity of its type locality, is about 125 feet, from which the
kness decreases northward to about 25 feet.

rum limestone member.[48] Succeeding the Cherryvale shale
ne easily recognized Drum limestone, which is characterized
rather persistent oölitic texture and by a distinctive fauna.
ally the Drum limestone is variable both in composition and
ure. Notwithstanding its individual peculiarities which
e it a desirable key horizon, the member does not have a
t stratigraphic value on account of its extreme variability
hickness and its local discontinuity. The Drum limestone
ecognized in the bluffs at Kansas City, where it is known
iliarly as "the oölite," and is very prominent in south-
ern Kansas in the vicinity of Coffeyville and Independence,
it has not been traced throughout its entire outcrop. The
m ranges in thickness from a very few feet, or nothing at
to as much as 80 feet, measured in Montgomery county.

hanute shale member.[49] Overlying the Drum limestone is
ther variable composite member which has been given the
ne Chanute shale. In the vicinity of its type locality at
nute it is a fine clay shale excellently adapted for brick
ufacture, but at Independence and other points the shale
ery sandy. East of Neosho river the Chanute is repre-
ed by a sandstone which constitutes the main mass of the
, and is exactly equivalent to the clay shales but a few
s distant.. Locally the Chanute shale contains much bitu-
ous matter and thin coal beds. In the vicinity of Thayer
coal is sufficiently important to be worked. The outcrop of
Chanute member is wide at the south and narrow at the
th. Its thickness, as observed in Kansas, varies from 25
00 feet, the maximum occurring toward the south, where
member apparently coalesces with the shale member over-
g the Iola. In the vicinity of Kansas City, Mo., the Cha-
e is represented by a succession of alternating shale and
limestone beds which are rather persistent locally.

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3. Adams, G. I.; loc. cit., p. 37. Named from Drum Creek, Montgomery county,
as.

9. Haworth, Erasmus, and Kirk, M. Z.; The Neosho River Section: Kan. Univ.
t., vol. 2, p. 109, 1894. Named from Chanute, Neosho county, Kansas.

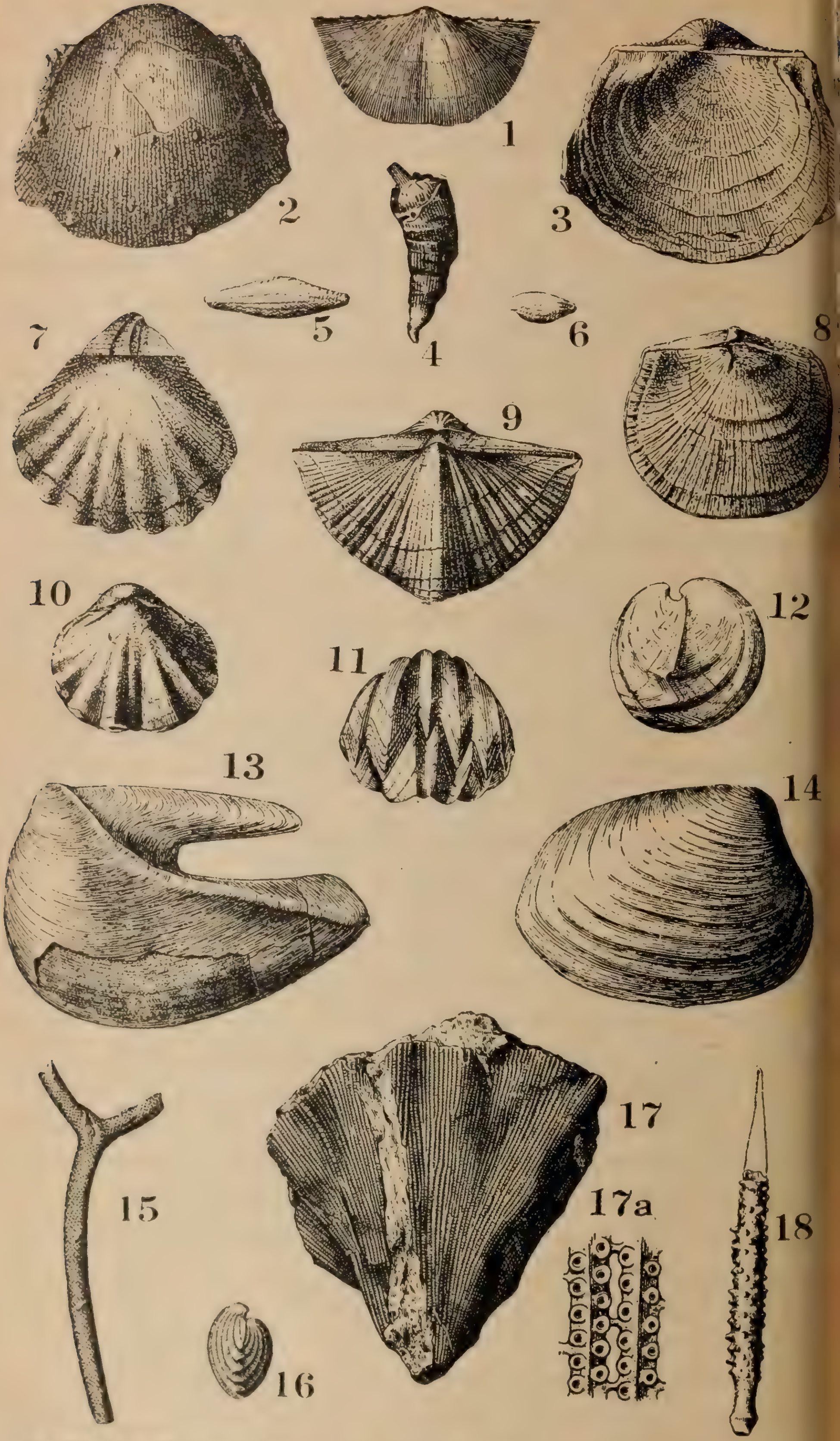

Plate V.—Typical fossils of the Lansing, Douglas, Shawnee and Wabaunsee formations.

a limestone member.[50] The top member of the Kansas
formation is the Iola limestone, a light gray, somewhat
alline, massive member which is very easily identified.
in general, rather free from joints, making it possible
tain large blocks in quarrying. The Iola limestone is very
tant to weathering agencies and forms a well-defined es-
nent along the line of its outcrop from Chanute and Iola
eastward to Kansas City. The escarpment crosses into
ouri at the southeast corner of Johnson county, but turns
vard up Kansas river to De Soto, and toward Leaven-
n on Missouri river as far as Walcott. Between Iola and
as City the member has a rather uniform thickness of
40 feet, but to the southwest and the northeast it becomes
much thinner or disappears. At Neodesha it is only one
six inches[51] thick. The Iola limestone is one of the best-
ed stratigraphic horizons in Kansas.

Lansing Formation.[52]

very important faunal break, clearly defined by Beede and
rs[53] and Girty,[54] occurs at the top of the Kansas City
ation. Accordingly the beds above the Iola limestone
n were formerly included in the Pottawatomie formation[55]

LANATION OF PLATE V. Protozoans: *Fusulina* sp., examples of the small spindle-
fossils which are so common in many of the Pennsylvanian and Permian limestones
sas, 5, 6. Corals: *Lophophyllum profundum,* a small horn coral with very
ent central axis or pseudocolumella which in broken or weathered specimens may
from the calyx, 4. Echinoids: *Archeocidaris aculeata,* example of a sea-urchin
hich is common in some beds. Bryozoans: *Fenestella shumardi,* a delicate colony
ace pattern type, natural size 17, enlarged fragment showing the apertures of the
ıal zoöids, 17*a*; *Rhombopora lepidodendroidea,* a slender branching growth with
ost microscopic apertures of the individual animals on all sides, each aperture rhom-
hape, 15. Brachiopods: *Productus cora,* a very common species with fine, somewhat
ribs, ventral valve 2, dorsal valve 3; *Chonetes granulfier,* a gently concavo-con-
ll with very fine radiating ribs and short diverging spines along the hinge line.
in extraordinary numbers in some formations in Kansas, ventral valve 1; *Meek-
iatocostata,* a shell of somewhat peculiar outline with large, rounded ribs marked
attern of finer ones, dorsal view 7; *Spirifer cameratus,* one of the most widely
ted and easily recognizable shells in the Pennsylvanian, its plications or ribs
into little bundles, dorsal view 9; *Enteletes hemiplicata,* a globose shell with small
beaks, coarse ribs which unite at the edges of the shell in a very jagged, zigzag
d the surface marked by fine striations which radiate from the beaks, dorsal view
nt view 11, side view 12; *Hustedia mormoni,* side view 16. Pelecypods: *Limop-
ngispina,* a peculiar bivalve with a very long anterior wing and forward pro-
of the shell, side view 13; *Edmondia aspenwallensis,* a rather evenly convex shell
ncentric ridges, side view 14.

Haworth, Erasmus, and Kirk, M. Z.; loc. cit., p. 109. Named from Iola, Allen
Kansas.

Haworth, Erasmus, and Bennett, John; loc. cit., p. 99.

Hinds, Henry, and Greene, F. C.; loc. cit., p. 28. Named from Lansing, Leaven-
county, Kansas.

Beede, J. W., and Rogers, A. F.; Coal Measures Faunal Studies, special report on
gas: Kan. Univ. Geol. Survey, vol. 9, p. 318, 1908.

Girty, George H., cited by Hinds, Henry, and Greene, F. C.; loc. cit., p. 155.

Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol.
vol. 3, p. 94, 1898. Also, Haworth, Erasmus, and Bennett, John; loc. cit., p. 75.

have been separated from the underlying beds and named from typical outcrops in the vicinity of Lansing, near Leavenworth the Lansing formation. Faunally, the Lansing formation appears to be continuous with the succeeding Douglas formation but as the latter differs lithologically from the Lansing, an has been defined in the literature for some time, it seems desirable to recognize both formations.

The Lansing formation has an approximate thickness of 140 feet in the north, but is somewhat less thick toward the south where the shale is less important. The formation appears a the surface in a rather narrow band, which crosses the state in a direction slightly west of south from Leavenworth to the vicinity of Sedan, in Chautauqua county. Four subdivisions two prominent limestone members and two shale members, are recognized.

The fossils of the Lansing are particularly noteworthy on account of the appearance of a number of new species which are very abundant in the upper Pennsylvanian of Kansas and the adjoining region. Among these may be mentioned especially *Chonetes granulifer, Enteletes hemiplicata* and the abundant *Fusulina* group (see plate V). Many of the common Pennsylvanian fossils may be found in the rocks of this formation.

Lane shale member.[56] At the base of the Lansing formation is the Lane shale, having an average thickness of 50 to 60 feet, but reaching a maximum of about 150 feet towards the south. The lower part of the member is clayey and the upper part somewhat sandy, but there are local variations. As a whole the member is rather free from sand.

Plattsburg limestone member.[57] This important limestone in the lower portion of the Lansing formation was defined by Broadhead, as early as 1862, from exposures at Plattsburg Mo., and although the name "Allen" limestone has been used by this survey in its early reports, it seems that there is no question of the priority of the term here employed. The Plattsburg is a fairly persistent horizon, but locally variable in its fea-

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[56] Haworth, Erasmus, and Kirk, M. Z.; The Stratigraphy of the Kansas Coal Measures: Kan. Univ. Quart., vol. 3, p. 277, 1895. Named from Lane, Franklin county, Kansas.

[57] Broadhead, G. C.; Coal Measures in Missouri: St. Louis Acad. Sci. Trans., vol. 2, pp. 317-327, 1868 (read May 5, 1862; first issued July 27, 1865). Named from Plattsburg, Clinton county, Missouri. The name Allen limestone has been applied to this member in earlier Kansas reports.

es. It is rather highly crystalline and massive and contains
ny fossils, the fauna being particularly interesting on ac-
nt of its many fossil sponges. It differs from ordinary
estone in that it breaks very readily into small angular frag-
nts. It is cherty in the upper part. The Plattsburg varies
ably in thickness, ranging from 4 or 5 feet in some areas to
or 80 in others. To the northwest in Missouri and to the
thwest in Oklahoma it gradually thins and disappears.

ilas shale member.[58] Separating the two limestone mem-
s of the Lansing is the lenticular Vilas shale, which ranges
hickness from 125 feet at a point south of Vilas to little
re than 5 feet in the bluffs of Fall river at Neodesha, and to
ost nothing farther south. It is notably thin also to the
theast, being only 5 feet at Kansas river and 3 or 4 feet in
ts of northwestern Missouri. Where the Vilas shale is very
n, a single escarpment is made by the overlying Stanton
estone and the underlying Plattsburg, but where the shale
ery thick the Stanton is weathered back four or five miles
m the outcrop of the Plattsburg. The Vilas shale is both
dy and clayey, and in places includes black slaty shale, with
n coal seams.

tanton limestone member.[59] The uppermost member of the
nsing formation is the Stanton limestone, composed of mas-
e limestone beds separated by thin slaty beds. The lime-
ne beds vary in thickness from 6 or 8 feet to 20 feet, and
persistent shale partings, which are rather rich in bi-
ninous matter, from 4 to 8 feet. The total thickness of the
nton varies from 20 to 40 feet, but it maintains a rather
form development from point to point. With the under-
ng Plattsburg member, the Stanton limestone forms one of
most prominent escarpments in eastern Kansas. It is
ced with readiness from the southern border of the state,
r Caney, to Neodesha, Altoona, and Benedict on Kansas
er, and from Kansas City northeastward across Missouri.
st of the escarpment there is an extensive dip slope, form-
a zone from five to twenty miles in width. The dip slope
the Stanton west of Olathe, covered by a thin mantle of
ale, extends all the way to Lawrence, a distance of nearly
rty miles.

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[58] Haworth, Erasmus, and Adams, G. Q.; Stratigraphy of the Kansas Coal Measures:
. Univ. Geol. Survey, vol. 3, p. 51, 1898. Named from Vilas, Wilson county, Kansas.

[59] Swallow, G. C.; Geological Report of Miami County, Kansas: Preliminary report
he Geol. Survey of Kansas, p. 75, 1866. Named from Stanton, Miami county, Kansas.

Douglas Formation.[60]

The Douglas formation is essentially a body of shale and sandstone with an important capping limestone member and a very thin, nonpersistent limestone in its middle portion. The outcrop of the formation is a northeast-southwest zone from 5 to 30 miles in width, limited by the escarpments of the Stanton and Oread limestone members. The limestone at the top of the formation, though one of the thickest and most persistent limestones in the Kansas Pennsylvanian, comprises but a small portion of the entire formation. The shale members of the Douglas are variable in composition and texture, changing markedly from point to point. In the north there is a predominance of clay shale, which is sufficiently pure locally for use in brick manufacture, but toward the south the proportion of sand is notably increased. In places here the shale is replaced by thick, massive sandstone. Coal occurs at one or two horizons in the formation, but is not of great thickness and has been worked only locally.

The thickness of the Douglas formation ranges from about 350 feet to 550 feet, 425 feet being an average. Like the subjacent formation, the Douglas includes four members of alternating shale and limestone.

The fossils of the Douglas formation are not very unlike those of the Lansing formation, although a number of species have been found in the Iatan limestone which are not reported from the lower beds. *Limopteria longispina*, a common form in the Douglas, does not occur above the Oread limestone. *Productus cora*, a long-ranging Pennsylvanian species, is very abundant in the Oread as are also species of *Fusulina*. A very interesting slender *Fusulina* resembling *F. longissima* is abundant in the lower Oread.

Weston shale member.[61] The lowest member of the Douglas formation is the Weston shale, named from typical outcrops on Missouri river above Leavenworth. It consists of clayey and sandy shale and ranges in thickness from 60 to 100 feet. The shale is soft and weathers readily, a noticeable escarpment being formed where the overlying Iatan limestone member is well developed.

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[60] Haworth, Erasmus: Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol. Survey, vol. 3, p. 93. 1898. Named from Douglas county, Kansas.

[61] Keyes, C. R.; The Missourian Series of the Carboniferous: Am. Geologist, vol. 23, pp. 298-316, 1899. Named from Weston, Platte county, Missouri. The name Le Roy shale has been used by Haworth for this member.

tan limestone member.[62] Overlying the Weston shale is thin Iatan limestone, called by Haworth and Bennett[63] the apoo limestone. In the north the Iatan is a dark to light limestone, thin and irregularly bedded or massive in char- r, weathering in large blocks. In Doniphan county, where persistent and well developed, it has a thickness of 15 At Lawrence and Ottawa it is but 3 or 4 feet thick and oints to the south is scarcely recognizable. However, it been identified in southern Kansas in the vicinity of In- ndence and elsewhere, where it forms a rather persistent zon.

wrence shale member.[64] The Lawrence shale consists of to 300 feet of argillaceous shale and sandstone, containing laces coal seams and thin but rather persistent beds of stone. The member is thinnest in the north and thickest e south, where it is very sandy. Coal in the Lawrence is of commercial importance in Franklin and Atchison ties. In Platte county, Missouri, there are interesting de- s of sandstone of Lawrence age[65] which lie unconformably the lower members of the Douglas and the upper mem- of the Lansing formations. These sandstones with the rlying basal conglomerates apparently represent deposits cient river channels, and indicate that the region in which occur was lifted above sea level during Lawrence time. the emergence was local and temporary is shown by the ed distribution of the sandstones and by the presence of read limestone above them.

ead limestone member.[66] The Oread limestone, consist- of three distinct limestone beds separated by shale beds, is of the most important divisions of the Upper Pennsyl- an in Kansas. The lower limestone bed is buff brown or in color, massively bedded, and 8 to 12 feet in thickness. it rests 20 to 60 feet of blue or drab shale. The middle stone of the Oread, which succeeds, has a uniform thick- of less than 3 feet, but is traced from the north to the

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Keyes, C. R.; ibid. Named from Iatan, Platte county, Missouri.

Haworth, Erasmus, and Bennett, John; loc. cit., p. 106.

Haworth, Erasmus, and Kirk, M. Z.; The Neosho River Section: Kan. Univ. , vol. 2, p. 110, 1894. Named from Lawrence, Douglas county, Kansas.

Hinds, Henry, and Greene, F. C.; loc. cit., p. 170.

Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. , vol. 2, pp. 123, 124, 1894. Named from Mount Oread, Lawrence, Kansas. The University is located on Mount Oread.

south limits of the state. The overlying shale is in part blue-gray and in part black, bituminous, and thinly bedded. It has a total thickness of 6 to 15 feet. The upper division of the Oread is a thin-bedded, cherty, buff limestone, 10 to 25 feet thick. It has uneven, wavy shale partings and is readily distinguished from the thick-bedded, essentially non-cherty lower Oread limestone. The average thickness of the entire member is 50 to 70 feet. It is resistant to erosion and forms a prominent escarpment extending entirely across Kansas.

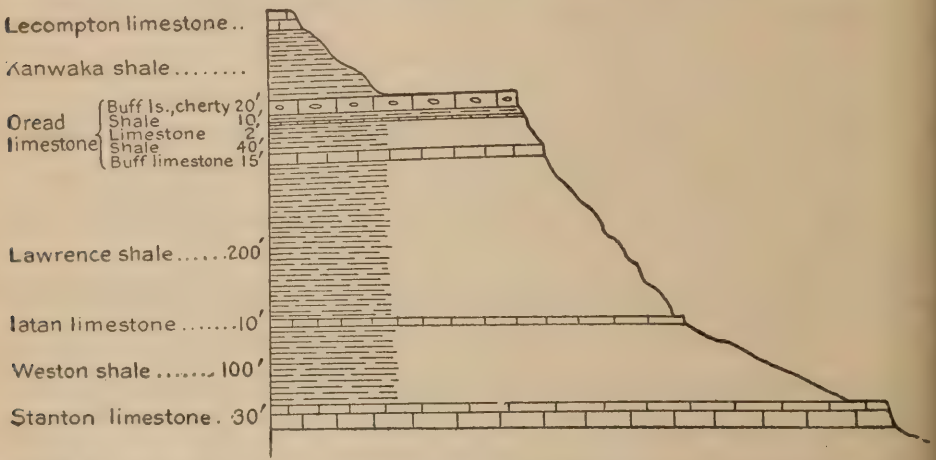

FIGURE 6.—Section of rocks exposed near Eudora and Lawrence, Kan. (U. S. Geol. Survey.)

Shawnee Formation.[67]

Immediately overlying the Douglas formation is the Shawnee formation, consisting of alternating limestone and shale members, most of which are traceable entirely across the state. Quantitatively the shales are much the most important, constituting more than three-fourths of the entire formation. The thin shale members are predominantly argillaceous or calcareous, the thick members arenaceous and micaceous. Black slaty shale and thin coal seams are found at a number of horizons in the formation. The Shawnee formation crops out in a broad belt extending from Doniphan and Atchison counties on the northeast to central Chautauqua county on the southwest. Subdivisions of the formation are well developed and persistent throughout the area of the Shawnee outcrop, but may be studied to best advantage where exposed in their type localities along Kansas river. The maximum thickness of the wnee is slightly more than 500 feet, but at certain localities possibly not more than 375 or 400 feet. It has been sugged by the paleontologic study of Beede and Rogers[68] that ipper boundary of the Shawnee formation should be drawn ie base of the Scranton shale instead of at the base of the eeding Burlingame limestone; but such a change in classiion has not been adopted formally. Nine subdivisions of nating shale and limestone are recognized in the Shawnee iation.

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[67] Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol. Survey, vol. 3, pp. 93, 94, 1898. Named from Shawnee county, Kansas.

ie fossils of the Shawnee, while including many of the mon Pennsylvanian forms of the lower formations, are difntiated by the appearance of more than a dozen new species the disappearance of nearly forty species which are found ie Douglas and lower formations. *Fusulina secalica* is very idant in the Lecompton limestone. *Chonetes granulifer* spines of *Archeocidaris* are very common in some of the stones. An interesting crinoid fauna, in many respects mbling that found in the Chanute shale of the Kansas City iation, is present in the Howard limestone. Some of the mon fossils of the Shawnee formation are among those trated in plate V.

anwaka shale member.[69] The basal member of the Shawormation is the Kanwaka shale, which consists of 50 to 100 of clayey shale and sandstone. Thin seams of coal have observed, but they have no commercial value. In northern sas the shale is calcareous and locally includes thin beds of ire limestone, but toward the south it is very sandy and well be termed sandstone. The name Elgin sandstone has suggested[70] for this phase of the member on account of sures near Elgin in southern Chautauqua county. Here sandstone is nearly 140 feet thick, but toward the south in homa it becomes thinner. The Elgin sandstone is probably "1,000-foot" sand of the Ponca City field and the "970-" sand of the Newkirk pool, in both of which areas it cons oil.[71]

. Beede, J. W., and Rogers, A. F.; Coal Measures Faunal Studies: Kan. Univ. Geol. y, vol. 9, pp. 345, 346, 1908.

. Adams, G. I.; Stratigraphy and Paleontology of the Upper Carboniferous Rocks stern Kansas: U. S. Geol. Survey, Bull. 211, p. 45, 1903. Named from Kanwaka hip, Douglas county, Kansas.

. Shannon, C. W., and Trout, L. E.; loc. cit., p. 90.

. Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol. y, vol. 3, p. 64, 1898.

Lecompton limestone member.[72] The Lecompton member consists of limestone and thin shale beds having a total thickness of 15 to 30 feet. The interbedded shales of the Lecompton increase in thickness toward the south. The limestone is yellowish gray in color and weathers to yellowish brown. It is fossiliferous, containing especially large numbers of *Fusulina* and sea-urchin spines. The beds are somewhat soft, and are sometimes reported by drillers as chalk rock.

Tecumseh shale member.[73] Arenaceous shales, or shaly sandstone ranging in thickness from 40 to 70 feet, overlie the Lecompton and are traced from Kansas river to the southern border of the state. This member, called the Tecumseh shale, weathers readily and a prominent escarpment is produced by the succeeding limestone.

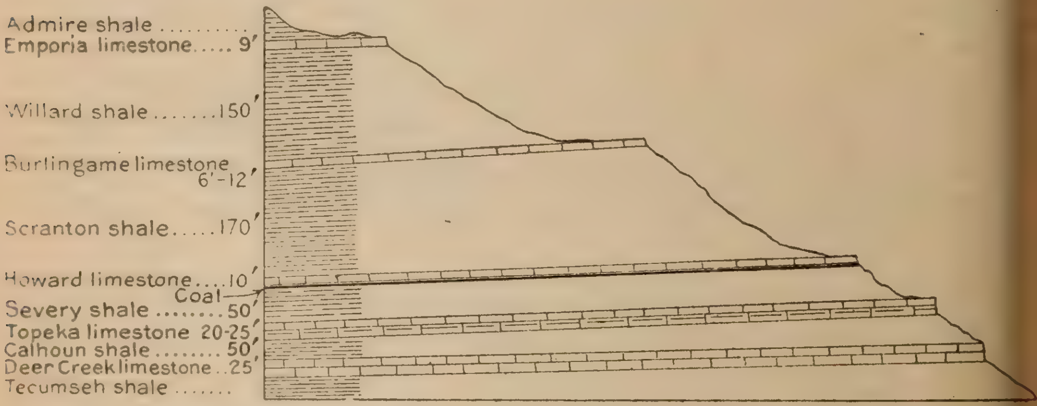

FIGURE 7.—Section showing the succession of rocks in the plateau south of Topeka, Kan. (U. S. Geol. Survey.)

Deer Creek limestone member.[74] Succeeding the Tecumseh shale are three limestone beds with thin intervening shale beds, which are grouped to form the Deer Creek limestone. The average thicknesses of the limestones from bottom to top, as measured along Kansas river are, respectively, 6, 2, and 5 feet, while that of the shales is 10 and 4 feet, making a total thickness of 20 to 30 feet for the member. The limestones of the Deer creek are buff or gray in color and rather thin-bedded. The upper bed is cherty and locally has an oölitic texture. In southern Kansas the Deer Creek limestone has a bluish color and is much jointed and broken.

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[72] Bennett, John: A Geologic Section from Baxter Springs to the Nebraska State Line: Kan. Univ. Geol. Survey, vol. 1, p. 116, 1896. Named from Lecompton, Douglas county, Kansas.

[73] Beede, J. W.: The Stratigraphy of Shawnee County, Kansas: Kan. Acad. Sci., Trans., vol. 15, pp. 27-34, 1898. Named from Tecumseh, Shawnee county, Kansas.

[74] Bennett, John: A Geologic Section from Baxter Springs to the Nebraska State Line: Kan. Univ. Geol. Survey, vol. 1, p. 117, 1896. Named from Deer creek, Shawnee county, Kansas.

'alhoun shale member.[75] The Calhoun shale overlying the er Creek limestone is a rather argillaceous shale, 50 feet k near its type locality on Kansas river, but thinner both he north and south. It contains thin beds of bluish limene in some localities.

'opeka limestone member.[76] The Topeka limestone comes 20 to 25 feet of blue and buff limestone with interbedded les, all of which, with the exception of a rather persistent er of black slaty shale, weathers to a deep buff color. The eka limestone does not form a prominent escarpment, but es part in the dip of the Deer Creek limestone.

every shale member.[77] The Severy shale, overlying the Toa limestone, varies in thickness from 40 to 60 feet. It is nly an argillaceous shale, but is locally quite sandy and the er part is in places very rich in bituminous matter. The ery shale member contains coal beds of good grade from 20 inches in thickness in the vicinity of Osage county, isas, and in parts of northwestern Missouri.

'oward limestone member.[78] Lying a few feet above the coal of the Severy shale at Scranton, Carbondale, Osage and Topeka is the Howard limestone member, consisting wo main limestone beds separated by 1 or 2 feet of shale. thickness of the whole member is but 3 to 7 feet, and its sistency is remarkable. The Howard is often reported in ling as solid limestone.

cranton shale member.[79] At the top of the Shawnee forma- is the Scranton shale member, 160 to 200 feet in thickness. lower part of the Scranton is prevailingly clay and sandy le or sandstone; the upper part contains a number of shales. Scranton shale is easily eroded, making prominent the sucling escarpment of the Burlingame limestone.

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5. Beede, J. W.; loc. cit., p. 29. Named from Calhoun, Shawnee county, Kansas.

6. Bennett, John; loc. cit., pp. 116, 117. Named from Topeka, Shawnee county, as.

7. Haworth, Erasmus; Stratigraphy of the Kansas Coal Measures (G. I. Adams' work): Kan. Univ. Geol. Survey, vol. 3, p. 67, 1898. Named from Severy, Green- county, Kansas.

8. Adams, G. I., quoted by Haworth, Erasmus; Stratigraphy of the Kansas Coal ures: Kan. Univ. Geol. Survey, vol. 3, p. 67, 1898. Named from Howard, Elk y, Kansas.

9. Haworth, Erasmus, and Bennett, John; loc. cit., p. 112. Named from Scranton, e county, Kansas.

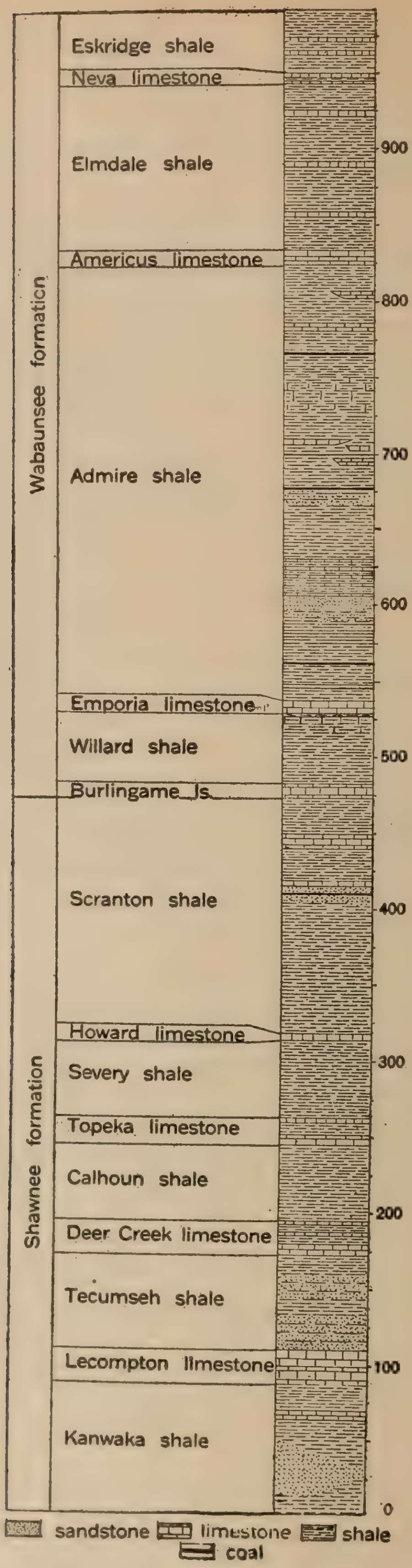

FIGURE 8.—Generalized section of the Shawnee and Wabaunsee formations of the Missouri group of the Pennsylvanian in Kansas.

Wabaunsee Formation.[80]

he Wabaunsee formation, comprising the upper portion of Pennsylvanian system in Kansas, has been defined to in- e the limestones and shales above the Howard limestone underlying the well-defined horizon of the Cottonwood stone. It is recognized that this grouping traverses a ked faunal change at the base of the Elmdale member,[81] that the lower limit of the formation does not coincide with faunal transition indicated by Beede and Rogers at the base he Scranton shale. It will doubtless be necessary to re- sify the stratigraphic divisions near the top of the Pennsyl- ian and the base of the Permian. However, in this report, ch is not primarily concerned with problems of stratig- ny, it does not seem wise to depart from the grouping pre- sly employed by this survey and the United States Geo- cal Survey.

he outcrop of the Wabaunsee, limited on the west by the ninent "Flint Hills" escarpment of the Cottonwood and ford limestones, appears as a north-south band across the e, wide at the north, but narrowing markedly toward the h. Important westward extensions occur up the valleys of sas and Cottonwood rivers. The thickness of the Wabaun- is about 500 feet. Eight members, consisting of rather limestones and thick shales, are recognized as distinct tigraphic units in Kansas.

he fauna of the Wabaunsee formation is distinguished by introduction of fossils which are closely related to the suc- ling Permian period. Indeed, the transition from the upper s here included in the Wabaunsee into the lower part of the mian is so gradual that there is lack of agreement as to the ise line of division. *Edmondia aspenwallensis, Hustedia moni, Derbya crassa, Chonetes granulifer, Fusulina* and a ber of other fossils are extremely common in parts of the nation. Some of the limestones and shales contain a very resting and abundant molluscan fauna. Certain beds are ost wholly made up of *Fusulina*. One of them, the Ameri- limestone, weathers readily and the loose shells of this little n may be scooped up in almost any quantity.

). Prosser, Chas. S.; The Classification of the Upper Paleozoic Rocks of Central as: Jour. Geology, vol. 3, pp. 682-705 and 764-800, 1895. Named from Wabaunsee y, Kansas.

1. Beede, J. W., and Rogers, A. F.; Coal Measures Faunal Studies: Kan. Univ. Survey, vol. 9, pp. 349, 432, 1908.

Burlingame limestone member.[82] At the base of the Wabaunsee is the persistent Burlingame limestone, 7 to 12 feet in thickness, composed of two main limestone layers, yellow or brown in color, separated by shale. It is a massive ledge which forms a prominent escarpment readily traced across the state.

Willard shale member.[83] The Willard shale is a rather thin member immediately above the Burlingame limestone, composed of blue and yellow shale, with a small amount of friable limestone. Its thickness in Lyon county, where it is typically developed, is about 45 or 55 feet.

Emporia limestone member.[84] Above the shale thus defined is about 9 feet of hard blue limestone of sufficient stratigraphic importance to receive recognition as a distinct member under the name Emporia limestone. The Emporia consists of two limestone beds, the lower 3 feet in thickness and the upper 2 feet, separated by about 4 feet of shale. It has been traced from Greenwood county across Lyon and Wabaunsee counties into Shawnee county. On account of its characteristic blue color it was called the "Emporia blue limestone" by Smith in his account of the geology of Lyon county.[85]

Admire shale member.[86] A thick succession of shale and sandstone with thin beds of limestone and coal is included in the Admire shale member. The total thickness of the member in Lyon county is approximately 300 feet. About 70 feet above the base of the Admire are five thin limestone beds called by Smith[87] "the Emporia system," and mapped by Adams[88] as the Emporia limestone. Some confusion has therefore arisen with regard to the true character of the Emporia member. It appears that the higher limestones are nonpersistent, not even extending across Lyon county, and are

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[82] Haworth, Erasmus: Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol. Survey, vol. 3, p. 72, 1898. (Extract from Hall's Osage River section, vol. 1.) Named from Burlingame, Osage county, Kansas.

[83] Beede, J. W.; The Stratigraphy of Shawnee County, Kansas: Kan. Acad. Sci., Trans., vol. 15, p. 31, 1898. Named from Willard, Shawnee county, Kansas.

[84] Kirk, M. Z.; A Geologic Section Along the Neosho and Cottonwood Rivers: Kan. Univ. Geol. Survey, vol. 1, p. 80, 1896. Named from Emporia, Lyon county, Kansas.

[85] Smith, Alva J.; Bulletin on Lyon County Geology, pp. 2-10. 1902. Also, Kan. Acad. Sci., Trans., vol. 17, p. 190, 1901.

[86] Adams, George I.; Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section: U. S. Geol. Survey, Bull. 211, p. 53, 1903. Named from Admire, Lyon county, Kansas.

[87] Smith, Alva J.; loc. cit.

[88] Adams, Geo. I.; loc. cit., p. 52.

ly entitled to rank as a distinct subdivision. The upper
on of the Admire consists of sandy shale and soft, massive
stone.

nericus limestone member.[89] Overlying the Admire shale
thin, rather persistent limestone 8 feet in thickness.
g its outcrop, at the edge of the escarpment which it
s over the Admire, it is characteristically broken into
blocks which are strewn down the slope beneath.

mdale shale member.[90] The Elmdale shale consists of ap-
imately 130 feet of variegated shale and thin interbedded
stone, the shale predominantly yellow to bluish in color,
imestone gray. About 30 feet above the base of the mem-
s a very friable limestone bed composed almost entirely
ie wheat-grain-like shells of the minute protozoan *Fusu-*
and about 30 feet higher there is a conspicuous yellow
stone. The Elmdale shale has been studied especially in
egion west of Cottonwood Falls, but has been recognized
considerable distance north and south.

va limestone member.[91] Succeeding the Elmdale shale are
beds of massive bluish-gray limestone, each a little more
4 feet in thickness, separated by about 2 feet of shale,
h form together the Neva limestone member. The lime-
makes a prominent bench and breaks off at the out-
in large rectangular blocks with rough, jagged surfaces.
weather to a very light color, which has been well likened
ie color of bleached bones. The Neva limestone becomes
ier to the north, but has been traced into Oklahoma far
h of the Kansas line. The southern portion of the Neva
ber in Oklahoma is, however, represented by sandstone.[92]
Neva limestone, or perhaps the Elmdale shale, should be
rded as the base of the Permian, according to Beede.[93]

kridge shale member.[94] Between the Neva and the suc-

. Kirk, M. Z.; ibid. Named from Americus, Lyon county, Kansas.

Prosser, Chas. S. (and Beede, J. W.); Revised Classification of the Upper
oic Formations of Kansas: Jour. Geology, vol. 10, p. 718, diagram, 1902. Named
Elmdale, Chase county, Kansas.

. Prosser, Chas. S., and Beede, J. W.; loc. cit., p. 718. Named from Neva, Chase
, Kansas.

. Beede, J. W.; The Neva Limestone in Northern Oklahoma, with remarks upon the
ation of the vertebrate fossil beds of the state: Okla. Geol. Survey, Bull. 21, pp.
1914.

. Beede, J. W.; loc. cit., p. 21.

. Prosser, Chas. S., and Beede, J. W.; loc. cit., p. 718. Named from Eskridge,
insee county, Kansas.

ceeding prominent limestone at the base of the Permian is the Eskridge shale member, 30 to 40 feet in thickness. The shale is green, brown or yellow in color, and being easily weathered like other shale members, is represented at its outcrop by a gentle, grass-covered slope. (Fig. 10.)

PERMIAN SYSTEM.

General Description.

Distribution. Adjacent to the Pennsylvanian outcrops on the west, and occupying an important zone in a north-south direction across central Kansas, is a group of rocks which are referred to the highest division of the Paleozoic era, the Permian period. This zone, narrow at the north where it is encroached from the west by the much younger beds of the Cretaceous, reaches its maximum width near the south border of the state, the Permian outcrop here extending from central Cowley county on the east to the west line of Clark county on the west. Thus the Permian of Kansas comprises a roughly triangular area with its apex at the north and its base on the south state line (see geologic map, plate I). In Oklahoma the Permian covers most of the western part of the state.

A knowledge of the Permian rocks is of vital importance to the oil producer because of their relation to the very valuable, recently discovered pools in Butler and Marion counties, and other districts within the area of the Permian outcrop. While large quantities of oil and gas have not thus far been discovered in the Permian itself in Kansas—although there is no inherent reason which precludes such discovery—rocks of the Permian must be drilled in any search for these fuels in central Kansas, and Permian rocks will probably be encountered in most tests of sufficient depth throughout the western part of the state.

Thickness. It is difficult to make any definite or general statement with regard to the thickness of the Permian in Kansas. Of course, the cover of Permian rocks is thinnest near the eastern border of the Permian outcrop, where only the lowest divisions are present, and thickest near the Cretaceous boundary. It appears also that the Permian is very thin in the north and reaches a maximum thickness in Kansas toward the south, in Sumner and Harper counties. A well drilled at Anthony, in Harper county, encountered 1,100 feet of red beds, salt and gypsum, and is the greatest single measurement of these rocks has been reported. Observation of surface outcrops ines an average total thickness of 1,100 feet for the lower ed Permian and about 1,200 feet for the upper red-beds ian.

hologic Character. The Permian of Kansas includes two distinct lithologic and stratigraphic divisions, a lower on consisting of marine shales, limestones and sandstones, ogically almost exactly like the underlying Pennsylvanian, n upper portion essentially composed of nonmarine red and sandstone. There are thick salt beds and some gypleposits in the upper part of the lower division (fig. 9), xtensive gypsum beds in the upper division. The marine ones and shales are chiefly developed in the northern and n part of the Permian outcrop, while the "red beds" are cted to the southwestern part of the Permian area in the A short distance south of Kansas the non-red Permian ones and shales disappear, being replaced by beds of red and sandstone. It appears that the red Permian rocks t entirely different in age from the non-red beds, though e most part they are distinctly younger. Indeed, there d beds of Pennsylvanian age in central Oklahoma which the coming of the conditions of red-bed sedimentation in egion even before Permian time.[95]

 Permian limestones are essentially like those of the ylvanian, with the exception that they are in general more filled with chert. The chert is so abundant in some ons that they might well be called chert members rather limestone members. The limestones are in most cases rained and noncrystalline. They are, like the limestone ers of the Pennsylvanian, rather thin but strikingly pert. In color they range from light gray or yellow to deep , and some of them are remarkably fossiliferous. The beds are quantitatively much the most important part of wer Permian, comprising practically the whole of the tions where the limestones thin out. They are argils rather than sandy, but grade locally into soft shaly tones. They vary in color from light gray, green or yel brown, and in a few cases reddish purple. The shales t very fossiliferous, as a rule, but some of the shale memare literally crowded with excellently preserved fossil

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 Snider. L. C.; The Gypsum and Salt of Oklahoma: Okla. Geol. Survey, Bull. 11, 1913.

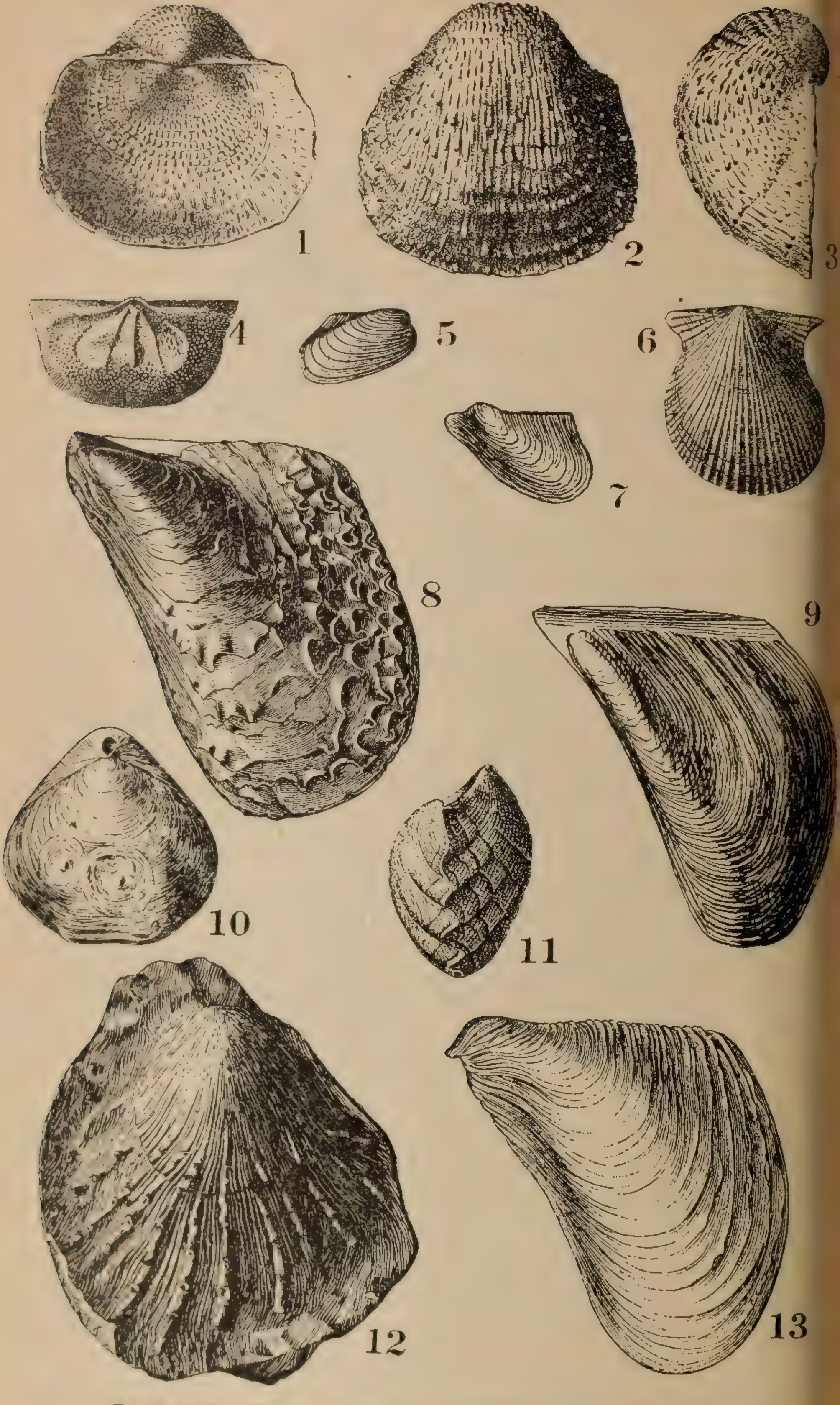

PLATE VI.—Typical fossils of the Permian in Kansas.

s. Sandstones are relatively unimportant and nonper-
nt. The salt beds are remarkably thick and pure in the
r part of the lower Permian, measuring about 400 feet in
thickness between Hutchinson and Kingman. The salt is
irt interbedded with shale, but with little associated gyp-
or limestone. The salt beds do not outcrop in any part of
tate, but have been recognized throughout a considerable
in deep drilling. Gypsum beds are of local occurrence and
ively slight thickness in the lower Permian. They are re-
ed from horizons underlying the salt beds in north central
sas.

e "red beds" division of the Permian, as indicated by the
generally applied, is chiefly characterized by the red
of the formations, both shale and sandstone. Limestone
nspicuously lacking. The shales are slaty or sandy and
e laterally in many places into sandstone. The sandstones,
h are most commonly cross-bedded, are irregular in thick-
and nonpersistent. Gypsum beds appear to be the only
y reliable stratigraphic makers, and where chiefly de-
ed—in southern Kansas and Oklahoma—they have been
in the subdivision and mapping of the group. The red-
gypsum of Kansas is best exposed in Clark, Comanche,
Barber counties. A thin member of dolomite is reported
e southwest part of the Permian outcrop in Kansas.

unal character. The fauna of the lower Permian is a de-
ive of that of the uppermost Pennsylvanian of the region,
is only distinguished from it by the presence of certain
ger types which belong to the new period. So gradual is
aunal transition from one system to the other in Kansas,
so unmarked by evidence of physical change, that the line
vision has long been unsettled. Final classification must
on extensive, careful and detailed paleontologic studies.
fossils have been found in the red beds of Kansas, but nu-
us discoveries in the similar beds of Oklahoma and Texas
ate without question the Permian age of this division.
fauna consists chiefly of vertebrates. Recently a good

PLANATION OF PLATE VI. Brachiopods: *Pustula nebrascensis,* one of the most
nt and widespread productids, the surface of which is covered with the bases of
erable spines, dorsal view 1, ventral view 2, side view 3; *Chonetes granulifer,*
r of dorsal valve 4 (see pl. V for exterior); *Composita subtilita* with two attached
of *Crania modesta,* one of the most ubiquitous brachiopods of the Pennsylvanian 10;
la striatocostata, side view 11 (see pl. V). Pelecypods:. *Pleurophorus ob-*
5; *Aviculopecten occidentalis,* 6 *Bakewellia parva,* 7; *Myalina kansasensis,* 8;
a permiana, 9; *Pseudomonotis hawni,* 12; *Myalina recurvirostris,* 13.

specimen of the well-known Permian reptile *Dimetrodon* has been found near Winfield, Cowley county, in the Winfield limestone.[96]

Subdivisions. The lower nonred division of the Permian is called the Big Blue group[97] from typical development along the river of that name between Pottawatomie and Riley counties, Kansas. The red beds division is included in the Cimarron group,[98] the name being taken from Cimarron river, which crosses the outcrop of the beds in southwestern Kansas and northwestern Oklahoma. The following table indicates the subdivisions of the Permian in Kansas as now defined.

SUBDIVISION OF THE PERMIAN SYSTEM IN KANSAS.

Group.	Formation.	Member.
CIMARRON.	Greer.	Big Basin sandstone shale.
	Woodward.	Day Creek dolomite. White Horse sandstone. Dog Creek shale.
	Cave Creek.	Shimer gypsum. Jenkins shale. Medicine Lodge gypsum.
	Enid.	Flowerpot shale. Cedar Hills sandstone. Salt Plain shale. Harper sandstone.
BIG BLUE.	Wellington.	Undifferentiated.
	Marion.	Pearl shale. Herington limestone. Enterprise shale. Luta limestone.
	Chase.	Winfield limestone. Doyle shale. Fort Riley limestone. Florence flint. Matfield shale. Wreford limestone.
	Council Grove.	Garrison shale and limestone. Cottonwood limestone.

BIG BLUE GROUP.

The general stratigraphic relations and lithologic character of the Big Blue group of the Permian has been sufficiently given in the foregoing general description. A more detailed nt of the subdivisions of the group, under appropriate ngs, follows. The formations recognized in Kansas are in number, named in order from below: Council Grove, e, Marion and Wellington.

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[96] Dunlevy, R. B.; personal communication.

[97] Cragin, F. W.; The Permian System in Kansas: Colo. Coll. Studies, vol. 6, pp. 3, 5, 1896.

[98] Cragin, F. W.; loc. cit., pp. 3, 18-48.

Council Grove Formation.[99]

the base of the Permian, as here defined, and resting con- ably on the subjacent Pennsylvanian, is the Council Grove ation, consisting of a very prominent, resistant and easily nized limestone member and a succeeding member of in- dded shale and limestone. The lower is termed the Cot- od limestone member and the upper the Garrison shale imestone member. The formation is most typically de- ed in the central portion of the state, but has been traced ut change a considerable distance to the north and south. ickness is about 150 feet. Its outcrop, which is very nar- n account of the very resistant character of the succeeding ord cherty limestone, forms a band bordering the east line Permian, and coincides approximately with the east face e so-called Flint Hills. The Council Grove formation s the transition in lithologic and faunal characters from ennsylvanian to the Permian.

tonwood limestone member.[100] The Cottonwood limestone of the most persistent and easily recognized horizons in as, its outcrop extending without break from Nebraska Oklahoma. The limestone is light gray or buff in color, vely bedded, and has an average thickness of about six The upper part of the member is almost entirely made up e small wheat- or rice-shaped protozoans, *Fusulina,* but are few other animal remains. The line of outcrop of the nwood is generally marked by a row of massive rectangu- locks of light gray or bleached, bone-colored limestone. se of its resistance to weathering, it forms a prominent pment. The persistence of the lithologic character of the nwood limestone is noteworthy.

rrison limestone and shale member.[101] Overlying the Cot- od are yellowish shales with thin intercalated limestone

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Prosser, Chas. S.; Revised Classification of the Upper Paleozoic Formations of : Jour. Geology, vol. 10, p. 718, 1902. Named from Council Grove, Morris Kansas.

Prosser, Chas. S.; loc. cit., pp. 711, 712. Named from Cottonwood river, Chase Kansas.

. Prosser, Chas. S.; loc. cit., p. 712. Named from Garrison, Pottawatomie Kansas.

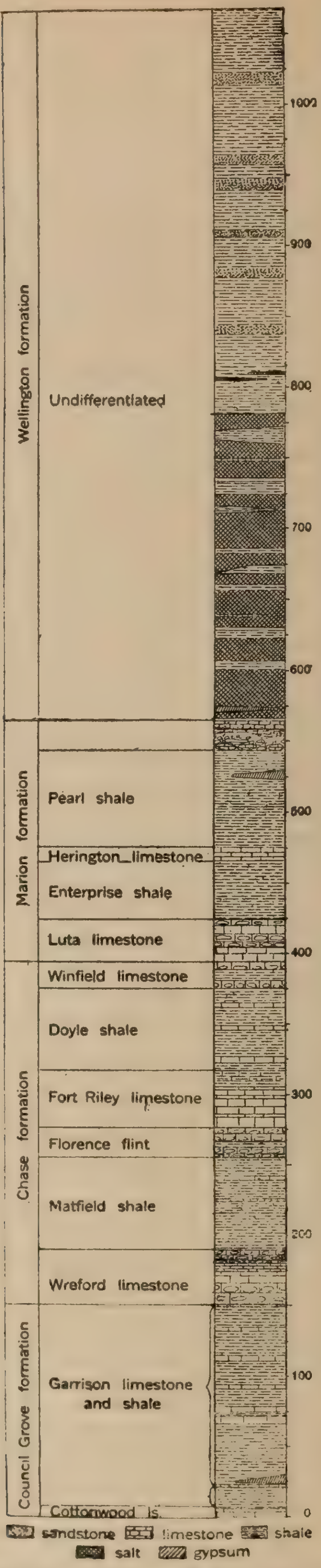

FIGURE 9.—Generalized section of the Big Blue group of the Permian in Kansas.

PLATE VII.—Permian limestone and shale in a bluff of Republican river, one quarter mile north of Wakefield, Clay county.

beds, which are included in the Garrison shale and limestone member. This division constitutes by far the greatest portion of the Council Grove formation, having a thickness of 135 to 150 feet. As recognized in the type area of the member, there are two main divisions in the Garrison—a lower shale, called the Florena shale bed, which is characterized by the abundance and fine preservation of its fossils, mostly belonging to a single brachiopod species, *Chonetes granulifer;* and an upper division, called the Neosho bed, consisting of green, chocolate or yellow shales alternating with thin beds of grayish limestone. Near the base of the Neosho bed in the Big Blue valley a bed of gypsum is found. The shales of the Garrison member weather readily and form the slope of the escarpment made by the overlying Wreford limestone.

Chase Formation.[102]

The Chase formation consists of a well-defined lithologic and faunal division of the Permian in Kansas. Lithologically, the abundance of limestone and hard, resistant chert is most noteworthy, the outcrop of this formation forming the most prominent topographic feature of central Kansas, the Flint Hills, which extend northward from Oklahoma almost to Nebraska. The eastern boundary of the formation approaches closely that of the Cottonwood limestone at the base of the Permian, and the outcrop as a whole is rather narrow on account of the resistant character of the upper members. In the north, where covered by glacial drift, the outcrop is somewhat obscured, but to the south the various members are clearly defined. The Chase formation has a thickness of about 230 to 270 feet.

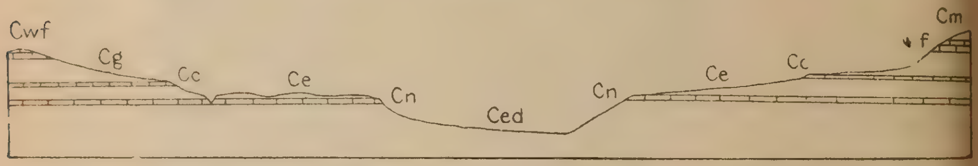

FIGURE 10.—Section across Cottonwood valley southwest of Elmdale, Kan., showing rock terraces or steps formed by resident limestone beds, and gentle slopes composed of shales. *Cm,* Matfield shale; *Cwf,* Wreford limestone; *Cg,* Garrison shale; *Cc,* Cottonwood limestone; *Ce,* Eskridge shale; *Cn,* Neva limestone; *Ced.* Elmdale shale. (U. S. Geol. Survey.)

Wreford limestone member.[103] The lowest subdivision of the

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[102] Prosser, Chas. S.; loc. cit., pp. 713, 714. Named from Chase county, Kansas.

[103] Hay, Robert; Geology and Mineral Resources of Kansas: Kan. State Board of Agric., 8th Biennial Report, 1891-'92, 1893. Named from Wreford, Geary county, Kansas.

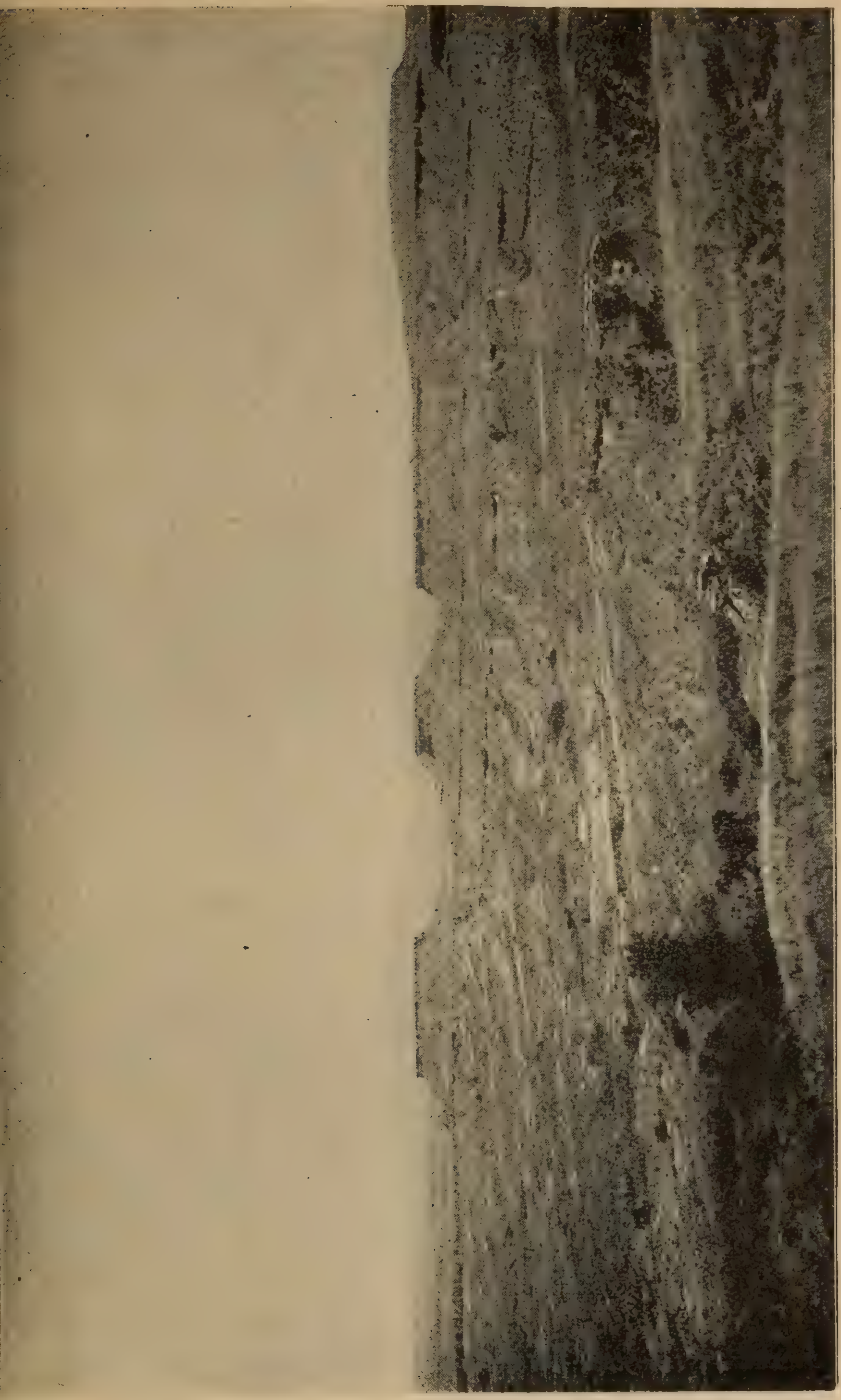

PLATE VIII.—Northern end of Gypsum hills, near Medicine Lodge, Barber county, showing typical badlands of the Permian red beds.

Chase formation is the Wreford limestone consisting of 35 t 50 feet of massive limestone and chert, or flint. As observe in most places, it is composed of three main beds, a chert limestone below and above separated by a heavy limeston nearly free from chert. Locally the middle non-cherty bed i replaced by a layer of shale. The rock is gray to buff in color massive and very resistant to weathering agencies. It form the first prominent escarpment above the Cottonwood limestone. Towards the south the Wreford is imperfectly solidified and weathers to a reddish brown, very porous rock.

Matfield shale member.[104] Overlying the Wreford limeston is the Matfield shale member, which includes 60 to 70 feet o variously colored shale and thin interbedded shaly and occasionally cherty limestones. This shale member forms the slop between the Wreford and the succeeding Florence flint, an does not have a wide outcrop at the surface.

Florence flint member.[105] This subdivision of the Chas formation consists of about 20 feet of very flinty limestone, number of layers being composed wholly of flint. Near th center of the member is a band of shaly, white, cellular limestone. Good exposures of the Florence flint occur at Oketo Grant, Valencia and Florence. The member is very resistant to erosion and forms a distinct escarpment with a well defined dip slope, which extends for some distance to the west Its outcrop closely parallels that of the Wreford limestone.

Fort Riley limestone member.[106] Massive buff limeston with thin interbedded shaly strata in the upper part is include in the Fort Riley limestone, measuring 40 to 45 feet in thickness. Near the center of the member are one or two ver massive layers which form a conspicuous bench at the outcrop, which is thus readily traceable for miles. The basal portion of the Fort Riley is either shaly or marly and is represented at Oketo, Marysville and Junction City by 6 to 9 feet o fossiliferous, calcareous shale.

Doyle shale member.[107] Overlying the Florence and the Fort members is about 60 feet of variously colored shale, called Doyle shale member. Grayish limestone beds appear in shale, but the member weathers rapidly and the outcrop ars as gently undulating prairie, in sharp contrast to the h topography produced by the massive limestone and flint below. The outcrop of the Doyle shale is also distinctly r than those of the immediately subjacent divisions. Lo- there are prominent and fairly persistent limestone beds e Doyle shale. One such bed, well exposed in the west of the El Dorado field near Towanda, which was of great tance in mapping the structure of the field, has been desig- l as the Towanda bed.

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[104] Prosser, Chas S. (and Beede, J. W.); loc. cit., p. 718, diagram. Named fron Matfield, Chase county, Kansas.

[105] Prosser, Chas. S.; The Classification of the Upper Paleozoic Rocks of Centra Kansas: Jour. Geology, vol. 3, p. 773, 1895. Named from Florence, Marion county Kansas.

[106] Swallow, G. C.; loc. cit., p. 14. Named from Fort Riley, Geary county, Kansas

[107] Prosser, Chas. S. (and Beede, J. W.); loc. cit., p. 718. Named from Doyle creek, Marion county, Kansas.

infield limestone member.[108] At the top of the Chase for- on is the highest chert horizon in the Kansas Permian, Winfield limestone, which consists of two main cherty stones separated by thin yellowish shale. North of Kansas , the Winfield limestone is not conspicuous and is ap- ntly much thinner than in the southern portion of the , where it forms a very conspicuous escarpment, well n in the vicinity of its type locality at Winfield in Cowley ty. The outcrop of the Winfield covers a much wider zone e south, also, than to the north. The chert of the Winfield t so uniform in character or so widely distributed as that e Wreford or Florence members, and in some localities orizon is represented simply by a prominent gray lime- . It may be traced across country either by the escarp- which it forms or from the zone of loose reddish-brown retions which in places stretch across the prairie. The ness of the Winfield limestone is about 20 to 25 feet.

Marion Formation.[109]

e Marion formation comprises the uppermost fossilifer- portion of the marine Permian of Kansas. It is a well- ed stratigraphic unit, clearly defined from the beds above below it. It lacks the very cherty character of the Chase ation, from which it is also clearly distinguished by its a, and is separated from the overlying Wellington forma- by its lack of salt beds, its light color and its content of limestone, which is practically absent in the Wellington. Marine invertebrate fossils are common in the Marion formation, but are very rare or lacking altogether in the Wellington. Buff, thin-bedded limestone and thick shale beds compose the Marion formation, well-developed beds of gypsum being present also in certain localities. A peculiar, somewhat variable conglomeratic limestone occurs at its top. The outcrop of the Marion is characterized by broad, rather gentle slopes, in decided contrast to that of the Chase formation in the Flint hills farther east. The formation has a total thickness of about 150 feet. The Marion has been divided into five stratigraphic subdivisions, a portion of which have been mapped.[110]

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[108] Prosser, Chas. S.; The Upper Permian: Kan. Univ. Geol. Survey, vol. 2, p. 64, Named from Winfield, Cowley county, Kansas.

[109] Prosser, Chas. S.; The Classification of the Upper Paleozoic Rocks of Central : Jour. Geology, vol. 3, p. 786, 1895. Named from Marion county, Kansas.

Luta limestone member.[111] Over a very considerable portion of central Kansas the Luta limestone forms the basal member of the Marion formation. It is a more or less cellular, soft, gray limestone, 30 feet in thickness, and contains siliceous geodes and layers of more or less abundant chert. The Luta limestone is well exposed in and about the town of Marion and is seen at Herington, from which point it may be traced north to Smoky Hill river. Southward it appears to become much thinner, being barely recognizable at Arkansas City and apparently disappearing in the section east of Newkirk, Okla.[112] The member is thickest at Marion.

Enterprise shale member.[113] Overlying the Luta limestone is the Enterprise shale, typically exposed in the vicinity of the town of Enterprise, Dickinson county, on Smoky Hill river. The member consists of variegated shale, green, yellow and maroon in color, and has an average thickness in the central portion of the state of 35 feet. It has been recognized as far south as Kay county, Oklahoma.[114] At Arkansas City the Enterprise shale is 44 feet thick.[115]

Herington limestone member.[116] Succeeding the Enterprise shale is a buff, massive, very fossiliferous limestone, which typical outcrops in the vicinity of Herington, north of on, has been called the Herington limestone. The member ite persistent and has been mapped from Smoky Hill river point south of Marion. It outcrops in the vicinity of Ar- as City, where it is about 15 feet thick. The average ness of the formation is 12 to 15 feet.

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[110] Beede, J. W.; Formations of the Marion Stage of the Kansas Permian: Kan. Acad. Sci., Trans., vol. 22, pp. 248-256, 1908.

[111] Beede, J. W.; loc. cit., p. 251. Named from Luta brook, which enters Antelope creek just north of Marion, Marion county, Kansas.

[112] Beede, J. W.; ibid.

[113] Beede, J. W.; loc. cit., p. 253. Named from Enterprise, Dickinson county, Kansas.

[114] Beede, J. W.; ibid.

[115] Beede, J. W.; Stratigraphy of the Eastern Outcrop of the Kansas Permian: Am. Geologist, vol. 36, p. 108, 1905.

[116] Beede, J. W.; ibid. Named from Herington, Dickinson county, Kansas.

arl shale member.[117] A succession of green, blue and red- shale, termed the Pearl shale member, overlies the Her- n limestone. On account of lack of resistance of the over- beds, outcrops of the Pearl shale are very uncommon. hickness of the member is estimated to be 70 feet. In the portion of the Pearl shale there are more or less per- it beds of limestone. These are the uppermost calcareous its of importance in the Permian of Kansas and mark the f division between the Marion and the succeeding Welling- ormation.[118]

Wellington Formation.[119]

e upper division of the Big Blue group is "a thick body of gray slate-colored shales" and important salt beds, to the name Wellington formation is given on account of pical development in the vicinity of the county seat of er county (fig. 10). By Haworth[120] and Kirk[121] the name ngton shale was restricted to the upper part of the forma- as here defined, and the lower strata were designated beds." Inasmuch as the salt deposits are very closely iated with the shales, it is regarded most desirable to all the beds above the Marion and beneath the "red beds" nit which may be called the Wellington formation. The trata do not appear at the surface, and therefore cannot apped, but may be considered as a subdivision of the ngton.

e outcrop of the Wellington formation occupies almost the western half of the Permian area in central Kansas the "red beds" Permian does not appear; but in the

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Beede, J. W.; loc. cit., p. 225. Named from Pearl, Dickinson county, Kansas.

It appears that the so-called Abilene conglomerate, which has previously been to the uppermost part of the Marion formation, is in reality a Tertiary deposit. ins fragments of rock which apparently belong to the Dakota sandstone and at no s it been observed in a stratigraphic position beneath the Wellington shale.

Cragin, F. W.; The Permian System in Kansas: Colo. College Studies, vol. 6, 896. Named from Wellington, Sumner county, Kansas.

Haworth, Erasmus; Geology of Kansas Salts, Mineral Resources of Kansas, 89: Kan. Univ. Geol. Survey, 1899.

Kirk, M. Z.; Kansas Salt, Mineral Resources of Kansas, 1898, pls. 5 and 6: niv. Geol. Survey, 1899.

southwest the Wellington is overlain by the Cimarron grou
west of Kingman and Harper counties. The formation h
not been mapped in the field and the precise limits of its ou
crops cannot be given, but it is known to be restricted esse
tially to the country south of Abilene—the outcrop extendi
only a short distance north of Smoky Hill river—and west of
line passing between Marion and Newton and east of Wichi
and Wellington. It is relatively a thick formation, amounti
in most places to more than 500 feet. The thickness of t
Wellington, as it appears, is much less in the north than in t
south, a condition which is probably due both to an origin
difference in thickness and to the covering of the uppermo
beds of the formation in the north by the eastward overlap
the Cretaceous strata. As indicated by well records,[122] t
thickness of the Wellington at Anthony is 799 feet, at Kingma
630 feet, at Hutchinson 578 feet, and at Kanopolis 485 fe
Prosser[123] estimates the thickness of the part of the Wellin
ton shale overlying the salt member in Saline county at abo
200 feet. As already indicated, the Wellington is chiefly
shale formation with thick salt beds in its lower portion. Lim
stone, though found in occasional thin layers, is not persiste
or abundant and in general is conspicuously lacking. The sha
is prevailingly blue, gray and yellow in color, with greenish a
reddish bands of various thicknesses. The gray or blue to
of the Wellington is in strong contrast to the prevailing r
color of the succeeding Cimarron beds. The shales are as
whole decidedly argillaceous in character.

CIMARRON GROUP.[124]

The upper or "red-beds" division of the Permian in Kansa
termed the Cimarron group, includes the surface rocks of
considerable area in southwestern Kansas. However, the ou
crop of the group in Kansas represents only the northern e
of a wide belt of red beds, which covers almost the entire wes
ern half of Oklahoma and reaches nearly to Pecos river
southwestern Texas.

So far as determined, the Cimarron rests conformably on t
subjacent Wellington formation, the line of contact crossi
the western part of Sumner and Sedgwick counties and t

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[122] Kirk, M. Z.; loc. cit.

[123] Prosser, Chas. S.; The Upper Permian: Kan. Univ. Geol. Survey, vol. 2, p.
1897.

[124] Cragin, F. W.; loc. cit., p. 3.

rn part of Reno and Kingman counties to Arkansas river.
group has not been recognized definitely north of Reno
y. On the west the Cimarron disappears beneath
ger formations belonging to the Comanchean, Cretaceous
ertiary, which unconformably overlie it. This western
lary traverses Kingman, Barber, Comanche, Clark and
e counties. Since red beds of probably Upper Permian
utcrop east of the Rocky Mountains in New Mexico and
ado, it is possible that the Cimarron group of Kansas is
uous beneath the overlying beds with these red strata to
est.

e total thickness of the Cimarron group cannot be ascer-
l accurately by observation of the outcrops because of the
ilarity of the stratification and lack of persistent trace-
orizons. The cross-bedded and lenticular character of
of the beds makes it very difficult also to determine the
In general the upper portion of the group is more regular
the lower, and the individual thicknesses of the various
visions in this part may be approximated rather closely.
ver, Cragin[125] studied carefully the various units of the
ds in southwestern Kansas, and estimated the total thick-
f the group at 1,280 to 1,330 feet. Well records at An-
, in Harper county, and Pratt, in Pratt county, appear to
l with Cragin's estimate.[126] Investigations by Prosser[127]
te that the total thickness of the Cimarron group in Kan-
more than 1,200 feet. In Oklahoma the Cimarron di-
is probably much thicker, as indicated by the work of
[128] and Snider.[129] The total thickness of the Permian red
lescribed by Gould is 2,250 feet, and Snider estimates the
num in central Oklahoma as at least 2,750 feet.

e Cimarron group is composed chiefly of red sandstones,
edded at certain horizons with fine elastic sediments.
andstone ranges in color from vermillion to maroon, and
red-brown color is often observed in many exposures.
ed shales are fine-grained, plastic and rather slightly con-
ted, though in some places they contain large quantities

Cragin, F. W.; loc. cit., p. 23.

Prosser, Chas. S.; loc. cit., p. 88.

Ibid., pp. 88, 89.

Gould, C. N.; Geology and Water Resources of Oklahoma: U. S. Geol. Survey,
upply Paper 148, pp. 34-88, 1904.

Snider, L. C.; The Gypsum and Salt of Oklahoma: Okla. Geol. Survey, Bull. 11,
107, 1913.

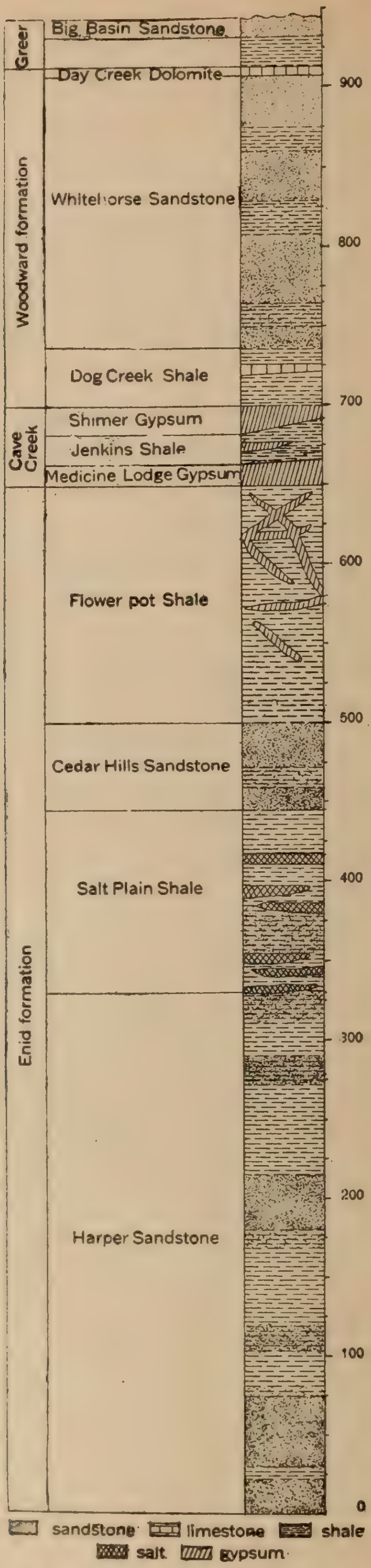

FIGURE 11.—Generalized section of the Cimarron group of the Permi in Kansas.

oluble salts. The color of the shales is lighter and in gen- l more brilliant than that of the sandstones.

Iost of the sandstone beds of the Cimarron are composed fine, well-rounded grains and are very commonly cross- ded, but locally they are coarse-grained or even conglomer- . The lenticular character of the sandstone beds is pro- nced and the irregularity of the bedding is such that it is ost impossible to trace a given horizon more than a short ance.

eds of gypsum cover considerable areas in the red-beds ıtry, but though they reach a thickness of as much as 60 at some places in Oklahoma,[130] gypsum is a relatively un- ortant part of the red beds as a whole. Beds of white or nish sandstone and shale are associated commonly with beds of gypsum. Dolomite members in the Cimarron of sas are thin and unimportant, but in Oklahoma they are e prominent. The dolomite is reported[131] to have a thick- of more than 100 feet in central Oklahoma.

wing to the absence of well-defined and persistent strati- hic horizons in the red beds of the Permian, it is difficult btain a satisfactory classification of the group. The sub- sions recognized in this report are based on the studies of gin and Gould in southern Kansas, and are those which it ıought will be most easily recognized and most useful in oration for oil and gas in the region.

Enid Formation.[132]

ıe lower portion of the Cimarron group from the Welling- shale to the lowest heavy gypsum bed is included in the l formation. Thus defined, the formation has a much ter thickness than any other division of the red beds in sas and covers a much larger area. It comprises essentially ıongypsiferous portion of the group.

ıe outcrop of the Enid formation in Kansas covers all or ions of Sumner, Kingman, Reno, Harper, Barber and anche counties, but the line of division separating it from succeeding formations has not been mapped in detail. It rs a very large area in northwestern and western Okla- a. The formation is largely composed of red shales, but

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). Snider, L. C.; loc. cit., p. 105.

. Cragin, F. W.; Observations on the Cimarron Series: Am. Geologist, vol. 19, , 1897.

. Gould, C. N.; loc. cit., p. 39. Named from Enid, Garfield county, Oklahoma.

lenticular beds of soft, red sandstones occur, especially in th lower part. The thickness of the Enid formation in Kansas i about 650 feet,[133] but measurements in Oklahoma by Gould[13 indicate a thickness of 1,500 feet in that state. The followin members are distinguished.

Harper sandstone member.[135] The basal part of the Eni formation, comprising almost its entire lower half, is terme the Harper sandstone member on account of exposures abou Harper, Harper county, Kansas. The member is by no mean wholly composed of sandstone, being largely made up of argillaceous and arenaceous shale. Both sandstone and shale ar prevailingly mottled dull red or reddish brown. The sandston beds, although soft, are sufficiently massive and firm to serve a building stone and have been quarried at Harper, Anthony an many towns in the region. In some portions of its outcrop the beds of the Harper member are reported to be distinctl saliferous like the succeeding shale.[136]

Salt Plain shale member.[137] Red shale, largely impregnate with salt, overlies the Harper sandstone and has been calle the Salt Plain shale member. According to Cragin,[138] th stratigraphic horizon of the shale and its outcrops at the surface are recognized by its large content of salt, which is suff ciently important to deserve the name "upper salt measures, the salt deposits of the Wellington shale being the "lower sal measures." The Salt Plain member outcrops on the east sid of the Cedar Hills, Harper county, on the Salt Fork of th Arkansas river, south of Aetna, and at various points in northern Oklahoma. Beds of rock salt encountered at a depth c about 700 feet in borings at Pratt probably belong to the Sa Plain of the Enid formation. The thickness of the membe is estimated by Cragin[139] as 1,555 feet, but it is probable tha the division cannot be differentiated clearly at all points fro adjoining parts of Enid.

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[133] Cragin, F. W.; The Permian System in Kansas: Colo. Coll. Studies, vol. p. 20, 1896.

[134] Gould, C. N.; loc. cit., p. 40.

[135] Cragin, F. W.; loc. cit., p. 18. Named from Harper, Harper county, Kansas.

[136] Cragin, F. W.; Observations on the Cimarron Series: Am. Geologist, vol. 1 p. 352, 1897.

[137] Cragin, F. W.; The Permian System in Kansas: Colo. Coll. Studies, vol. pp. 20, 23, 1896. Named from the Salt Plain of Cimarron river, Woodward count Oklahoma.

[138] Cragin, F. W.; loc. cit., p. 22.

[139] Cragin, F. W.; loc. cit., p. 23.

edar Hills sandstone member.[140] Above the saliferous les of the Salt Plain member is a zone of hard, bright-red, -grained sandstone, which has been given the name Cedar s sandstone by Cragin. The member is rather massively ded, and, according to Cragin, has locally a marked con- ionary structure. Excellent exposures occur northwest of elton, Kan., in the upper part of the Cedar hills, in the sum hills southwest of Medicine Lodge and southeast of na. The thickness of the member is about 50 to 60 feet.

lowerpot shale member.[141] At the summit of the Enid for- ion occur gypsiferous clay beds, named by Cragin the werpot shales, from exposures at the mound of that name he Gypsum hills southwest of Medicine Lodge. The clay les show variegated tints ranging from light gray to dark wn, but red is very much in predominance. Thin beds and quely intersecting veins of gypsum occur throughout the nber. The clays yield very readily to weathering agencies, ning many peculiar and striking erosion features. The werpot shale outcrops in the escarpment of the Gypsum and northwestward in the bluffs of Medicine Lodge river its tributaries to a point a few miles south of Belvidere. s well exposed along the Salt Fork, at Cimarron and its utaries, and extends south into Oklahoma. The thickness he shale is about 150 feet.[142]

Cave Creek Formation.[143]

he Cave Creek formation is the chief gypsum-bearing divi- of the Permian red beds in Kansas. As defined by gin,[144] it consists typically of red shale with gypsum beds some thin ledges of dolomite. On account of the compara- resistance of the gypsum beds to weathering agencies, the nation forms a pronounced escarpment throughout almost entire extent of its outcrop, and is therefore easily dif- entiated from associated beds of the Cimarron group. In isas and northern Oklahoma, the Gypsum hills and Glass intains mark this outcrop, which varies in width from one

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40. Cragin, F. W.; loc. cit., p. 24. Named from Cedar Hills, Harper county, Kansas

41. Cragin, F. W.; loc. cit., p. 24-27. Named from Flowerpot Mound, between East West Cedar creeks, Barber county, Kansas.

42. Cragin, F. W.; loc. cit., p. 27.

43. Cragin, F. W.; loc. cit., p. 27. Named from Cave creek, Comanche county, as.

44. Cragin, F. W.; loc. cit., pp. 27, 28. Also, Observations on the Cimarron series: Geologist, vol. 19, pp. 356, 358, 1897.

to eight miles. Excellent exposures occur on the south side of the Salt Fork of Arkansas river and Cimarron river near the state line. The outcrop of the gypsum beds trends north and northwest from southeastern Barber county to a point about 30 miles northwest of Medicine Lodge, where the Permian beds disappear beneath the Comanchean and Tertiary deposits. The thickness of the Cave Creek formation ranges from 50 to 100 feet, the average being about 70 feet. Three gypsum members, separated by red shale beds, have been distinguished in Oklahoma,[145] but in Kansas only two gypsums, the Medicine Lodge bed below and the Shimer bed above, are recognized.

Medicine Lodge gypsum member.[146] The lower massive gypsum bed of the Cave Creek formation in Kansas is the most conspicuous gypsum deposit in the Permian. It is pure white to gray in color, locally with mottlings of dark reddish brown, and is very hard and fine-grained. Because of its resistance to erosion, the gypsum forms the cap rock of hills and high buttes. In many places, however, there are large solution caverns which are comparable in size and complexity to caves in limestone formations. The Medicine Lodge gypsum extends uninterruptedly from near the head of Medicine Lodge river, in Kansas, to Canadian county, southern Oklahoma, and is therefore one of the most persistent and well-defined stratigraphic horizons in the "red beds." The thickness of the Medicine Lodge gypsum ranges from 2 to 30 feet.[147]

Jenkins shale member.[148] Red clay shale, having a thickness ranging from 4 to 5 feet to more than 50 feet, separates the persistent gypsum members of the Cave Creek formation. It is termed the Jenkins shale member.

Shimer gypsum member.[149] The upper gypsum of the Cave Creek formation is essentially the same in physical and chemi-

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145. The equivalent of the Cave Creek formation in Oklahoma has been called the Blaine formation by Gould (Oklahoma gypsum: Second Bien. Rept., Okla. Dept. Geol. and Nat. Hist., 1902). A thin gypsum bed, the stratigraphic equivalent of the upper Enid formation in the south, but to the north the Blaine is identical with Cragin's Cave Creek formation (Gould, C. N., Geology and Water Resources of Oklahoma: U. S. Geol. Survey, Water Supply Paper 148, p. 44, 1905). The latter name, having priority, is the one here used.

146. Cragin, F. W.; The Permian System in Kansas: Colo. Coll. Studies, vol. 6, pp. 28-39, 1896. Named from exposures on Medicine Lodge river in the vicinity of Medicine Lodge, Barber county, Kansas.

147. Cragin, F. W.; loc. cit., p. 27.

148. Cragin, F. W.; loc. cit., p. 28. Named from the former Jenkins post office, near Cave creek, Barber county, Kansas.

149. Cragin, F. W.; loc. cit., p. 27. Named from Shimer township, Barber county, Kansas.

acters as the Medicine Lodge member. Its thickness, from 4 to 25 feet, is, however, not so great, but it is s widely distributed. A thin dolomite bed is found at of the gypsum in many exposures. In general the gypsum outcrops somewhat back from the brow of .

Woodward Formation.[150]

the Cave Creek gypsums are found red shale, sand- d dolomite, which have been called the Woodward for- The formation contains no gypsum beds, its upper ng defined by the lowest gypsum bed of the succeed- r formation. In Oklahoma the Woodward is charac- y the prominence of dolomites as well as the absence m beds. The sandstones are fine-grained and, like s, brilliant red in color. Where uncovered by pro- ayers of harder strata the beds are carved into very and in many cases grotesque forms. The outcrop rmation in Kansas is found in northwestern Barber long the upper course of Medicine Lodge river, across omanche county, and in southeastern Clark county in y of Cimarron river. The general dip of the strata in on is to the south. The thickness of the Woodward n is about 200 to 250 feet in Kansas, but in Oklahoma xcess of 300 feet.[151]

members are, under the present classification of the ferred to the Woodward, the Dog Creek shale below, tehorse sandstone in the middle portion, and the Day lomite above. Recent studies, chiefly by Beede,[152] of on of the Woodward, indicate that a very important mity exists at the base of the Whitehorse sandstone. nber, therefore, should doubtless not be included with Creek shale beneath, which should probably be con- he upper part of the Cave Creek division. Further the Permian "red beds" area in southwestern Kansas, planned at this time, will doubtless give additional this problem. In the absence of definite information, may be classified at least for the present as they have y been reported.

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ld, C. N.; Oklahoma Gypsum: Sec. Bien. Rept., Dept. of Geol. and Nat. Named from Woodward county, Oklahoma.

ld, C. N.; Geology and Water Resources of Oklahoma: U. S. Geol. Survey, y Paper 148, p. 52, 1905.

de, J. W.; unpublished manuscript and personal communication.

Dog Creek shale member.[153] The basal portion of the Woo ward formation consists of dull-red argillaceous shale with o or two thin, discontinuous ledges of dolomitic limestone. Th member, the Dog Creek shale, has an average thickness about 30 feet[154] in southern Kansas, but in central Oklahon there is a notable increase in the proportion and thickness the dolomite,[155] and measurements by Gould[156] indicate a tot thickness for the member of 175 to 225 feet.

Whitehorse sandstone member.[157] The middle division of tl Woodward, originally known as the Red Bluff sandstone,[1 comprises the largest portion of the formation. It consists 175 to 200 feet of very fine-grained, light-red sandstone ar sandy shale, irregularly stratified and cross-bedded. Tl Whitehorse member exhibits the most intense vivid coloratic of any division of the series. Locally the sandstone is suff ciently strong for building stone. In general it is readil eroded and forms conspicuous buttes and mesas. On Medicir Lodge river and as far west as Belvidere, the Whitehorse sanc stone immediately underlies the Comanchean, but its thicl ness has been reduced by pre-Comanchean erosion. Outcroj are numerous along Mule creek and on Salt Fork and tribu taries, in Barber and Comanche counties, north of Cimarro river, across central Clark county, and reaching to lowe Crooked creek in Meade county.[159]

Day Creek dolomite member.[160] The upper part of the Wooc ward formation in Kansas and Oklahoma is a conspicuous an persistent ledge of hard, white dolomite. Weathered ex posures are gray, and in many cases have a somewhat pinkis or reddish tinge. It is very compact and breaks with a cor choidal fracture like flinty chert. The thickness of the Da Creek dolomite is only 1 to 5 feet, but on account of its peculia lithologic characters and persistence it is a valuable horizo marker. The outcrop extends westward across north centra Clark county to southeastern Meade county.

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[153] Cragin, F. W.; loc. cit., p. 39. Named from Dog creek, Barber county, Kansa

[154] Cragin, F. W.; loc. cit., p. 39.

[155] Cragin, F. W.; Observations on the Cimarron Series: Am. Geologist, vol. 1 p. 358, 1897.

[156] Gould, C. N.; loc. cit., pp. 54, 55.

[157] Gould, C. N.; loc. cit., p. 52. Named from Whitehorse Springs, Woods count Oklahoma.

[158] Cragin, F. W.; The Permian System in Kansas: Colo. Coll. Studies, vol. p. 40, 1896. The name Red Bluff has previously been used for another formation.

[159] Cragin, F. W.; loc. cit., p. 43.

[160] Cragin, F. W.; loc. cit., p. 44. Named from Day creek, Clark county, Kansa

Greer Formation.[161]

ove the Day Creek dolomite, in southwest Kansas, are 25 feet of red shale and sandstone which are with little doubt stratigraphic equivalent of the Greer formation of Okla- , the upper gypsum series of that state. The exposed of the uppermost Permian in Kansas do not contain um. The outcrop of the formation is found in Clark ty, exposures specially noted by Cragin[162] occurring near unction of Buff and Hackberry creeks, Kiger creek and creek. Rocks observed on Crooked creek, in southeastern le county, may belong to this horizon.[163] It is to be noted a considerable thickness of Permian red beds, younger the probable representative of the Greer formation in as, is exposed in western Oklahoma.[164] An unknown ness of Permian strata has been removed by the erosion h preceded the Comanchean depositions in Kansas. It is ble that a greater amount of the upper red beds are pres- eneath the covering of younger sediments in the western of the state than are exposed in the area of Permian out- The Greer formation in Kansas includes two members, stinguished by Cragin.

named shale member.[165] The lower member of the Greer sts of maroon-colored shale, which characteristically hers into small crumbling fragments. Its exposed thick- is not more than 20 feet.

g Basin sandstone member.[166] Above the shale is a rather ive sandstone, red or grayish white in color. It is ex- l at a number of localities in Clark county, where on the it underlies the sandstone of the Comanchean. Its maxi- measured thickness is 12 feet.

COMANCHEAN SYSTEM.

pearing at the surface in Barber, Comanche, Kiowa, Clark Meade counties, Kansas, and continuing thence in a south- erly direction into Oklahoma, is a not very thick succession

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. Gould, C. N.; Oklahoma Gypsum: Sec. Bien. Rept., Okla. Dept. Geol. and Nat. 1902. Named from Greer county, Oklahoma.

. Cragin, F. W.; loc. cit., pp. 46-48.

. Cragin, F. W.; loc. cit., p. 47.

. The gypsum-bearing Greer formation and the succeeding Quartermaster forma- Oklahoma, both of Permian age, have a combined thickness of 500 to 600 feet. , C. N.; Geology and Water Resources of Oklahoma: U. S. Geol. Survey, Water paper 148, pp. 59, 1905.)

. This shale has previously been called the Hackberry shale, a name which is cable on account of its prior use for an Upper Devonian division of Iowa.

. Cragin, F. W., loc. cit., p. 46. Named from Big Basin, Clark county, Kansas.

of sandstone and shale beds which by their contained fossils appear to represent some portion of the well-developed Comanchean system of the Texas region. The belt of outcrop of these beds pursues an irregular westward course on the north side of Medicine Lodge river from a point a few miles northeast of the town of Medicine Lodge into southeastern Kiowa county, southeastward a considerable distance on the south side of Medicine Lodge river, then turns west. An outlier covering some square miles is found in southern Comanche county. The northward extent of the Comanchean beds is undetermined on account of the widespread cover of younger strata. Scientific interest attaches to the discovery of fossiliferous beds resembling the Comanchean in northern McPherson and Saline counties along Smoky Hill river. The age and the general character of these, the so-called Mentor beds,[167] are not satisfactorily determined.

The Comanchean of southwestern Kansas is composed of two formations, which may be distinguished readily both by lithologic and paleontologic characters. At the base, resting with distinctly marked unconformity on the eroded surface of the subjacent Permian red beds, is a sandstone which varies in thickness from 40 to 70 feet. This division has been called the Cheyenne sandstone.[168] The upper division consists of calcareous shale 125 to 140 feet in thickness, which in the eastern portion of the Comanchean area, in Kansas especially, passes at its base into a shelly, fossiliferous limestone. The formation is termed the Kiowa shale.[169] In the eastern portion of its outcrop it rests on the Cheyenne sandstone. Farther west it immediately overlies red beds of the Permian Cimarron group. Above the Kiowa shale is found brown sandstone of Dakota age, or Tertiary and Pleistocene sand, gravel and other deposits.

The total thickness of the Comanchean beds as observed in southwestern Kansas is not, then, more than 300 feet, and throughout the greater portion of its extent the division has an average thickness of less than 200 feet. It is probable that within a few miles to the north these beds pinch out entirely.

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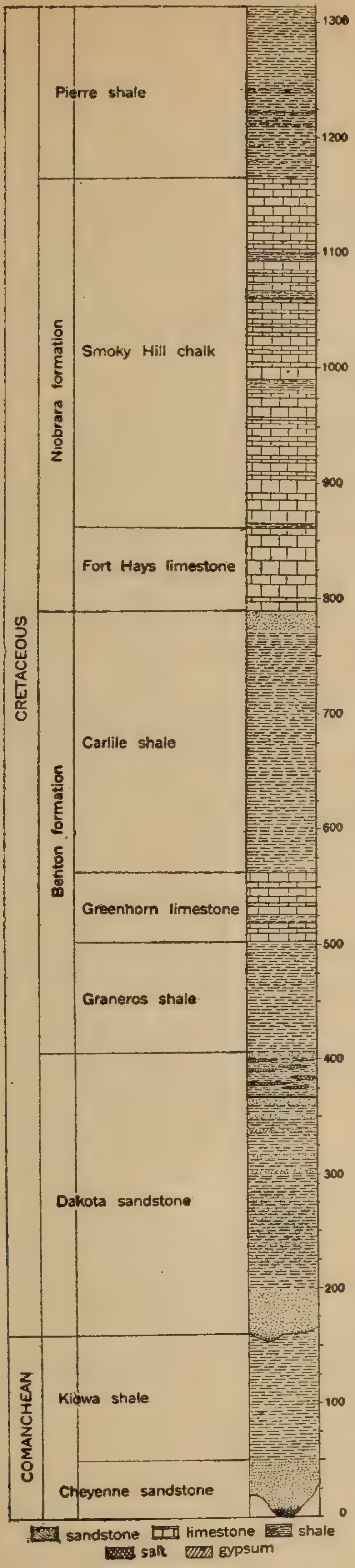
[167] Cragin, F. W.; The Mentor Beds—a Central Kansas Terrane of the Comanche Series: Am. Geologist, vol. 16, p. 162, 1895.

[168] Cragin, F. W.; Contributions to the Paleontology of the Plains, No. 1: Washburn Coll. Lab. Nat. Hist., Bull., vol. 2, pp. 65-68, 1889. Named from the Cheyenne rock at Belvidere, Kiowa county, Kansas.

[169] Cragin, F. W.; Descriptions of the Invertebrate Fossils From the Comanche Series in Texas, Kansas and Indian Territory: Colo. Coll. Studies, vol. 5, p. 49, 1894. Named from Kiowa county, Kansas.



GURE 12.—Generalized section of the Comanchean and Cretaceous systems in Kansas.

Careful studies made by Cragin,[170] Hill[171] and Prosser[172] indicate that the Comanchean beds of Kansas should be regarde as the attenuated equivalent of the uppermost or Washita division of the Texas Comanchean.

Cheyenne Sandstone.

The Cheyenne sandstone is the lower, sandy division of th Comanchean rocks in southwestern Kansas (fig. 12). It i found chiefly in the eastern part of the Comanchean area, bein undeveloped for the greater part, in Clark and Meade countie where the Kiowa shale rests directly on the Permian red beds The Cheyenne formation is in the main a rather coarse grained, friable sandstone, yellowish gray to whitish in color but in many exposures spotted and striped with colors such a purple, crimson or brown. In places it is conspicuously cross bedded. Some layers in the formation are more firmly cemente than associated ones and stand out prominently on weathere exposures. The outcrop is characteristically rugged and carve by erosion into various forms. Fossil wood and imprints o leaves resembling leaves from the Dakota sandstone are foun at different localities in the Cheyenne. The maximum observe thickness of the formation is about 70 feet,[173] but its averag ranges from 40 to 55 feet.

Kiowa Shale.

The upper portion of the Kansas Comanchean consists o shaly material. The rocks composing this, the Kiowa shale, are as widely distributed in the state as the Comanchean, and are found in places overlying the Cheyenne sandstone, elsewhere resting directly on the Permian red beds. Over a large area there is found at the base of the formation a very calcareous zone filled with invertebrate fossils. This, called by Cragin[174] the Champion shell bed, is essentially a limestone member and rded as the probable equivalent of the Comanche Peak ne of Texas.[175]

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[170] Cragin, F. W.; On the Cheyenne Sandstone and the Neocomian Shales of Kansas Am. Geologist, vol. 6, pp. 233-238, vol. 7, pp. 23-33, 1890. Further Notes on the Cheyenne Sandstone and Neocomian Shales; Am. Geologist, vol. 7, pp. 179-181, 1891 Descriptions of the Invertebrate Fossils from the Comanche Series in Texas, Kansas and Indian Territory: Colo. Coll. Studies, vol. 5, pp. 49-68, 1894. A Study of the Belvidere Beds (Kansas): Am. Geologist, vol. 16, pp. 357-385, 1895.

[171] Hill, Robert T.; On the Outlying Areas of the Comanche Series in Kansas, Oklahoma and New Mexico: Am. Jour. Sci., 4, vol. 1, pp. 205-234, 1895.

[172] Prosser, Chas. S.; Comanche Series of Kansas: Kan. Univ. Geol. Survey, vol. 2 pp. 96-181, 1897.

[173] Prosser, Chas. S.; loc. cit., p. 112.

[174] Cragin, F. W.; A Study of the Belvidere Beds (Kansas): Am. Geologist, vol. 16, p. 368, 1895.

e the fossiliferous calcareous zone is black, laminated, ceous shale, which gradually changes upward to bluish ayish, slightly arenaceous shale. The upper part of the ion consists of fossiliferous yellowish-gray shale with yers of yellowish or pinkish limestone. The maximum ss of the Kiowa shale is 150 feet, measured on Bluff in Clark county,[176] the average being about 125 or 130

CRETACEOUS SYSTEM.

General Description.

ribution. Occupying an area of nearly 25,000 square n north central Kansas, and appearing at the surface in tracts at various places in the western part of the are strata belonging to the Cretaceous system. The boundary of the Cretaceous outcrop is a very irregular ending southwest from Washington county to Reno . Important outliers occur in Saline, Dickinson, Marion cPherson counties. To the south and west the Cre- s is concealed by a widespread mantle of Tertiary sands, s and other deposits. Along many of the streams, how- specially the main lines of drainage, the Tertiary cover en removed by erosion, exposing the Cretaceous in long, arms. Along Smoky Hill river, for example, Cre- s strata are exposed to the west beyond the Colorado ne. The small areas of Cretaceous outcrops surrounded tiary, which occur both to the north and south of the Hill, are found mainly where streams have cut through erlying Tertiary.

kness. The maximum thickness of the Cretaceous rocks nsas is probably not more than 1,300 feet, but since the nost formation, the Pierre shale, is restricted to the vestern portion of the state, it is certain that the thick- f the Cretaceous in the main area of its outcrop is very ess. In general, greater thicknesses are to be measured ding to the west, where successively higher divisions of stem are encountered. The thickness of the individual tions appears to remain fairly constant, so that measure-

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Cragin, F. W.; letter to Prosser, Chas. S.; Comanche Series of Kansas: Univ. vey, vol. 2, p. 114, 1897.

Cragin, F. W.; ibid., p. 115.

ments made at the outcrop closely approximate the record of thickness obtained from well-logs a hundred or more miles distant. The average thickness of the Cretaceous formations in Kansas is shown on the accompanying generalized section (fig. 12).

Lithologic character. The Cretaceous system is composed of clayey and sandy shale, chalky limestone and sandstone, named in the order of their quantitative importance in the section.

The shales are, for the most part, rather dark in color, ranging from dark blue-gray or brown to black. The "somber" color of some of the Cretaceous shale divisions is a characteristic feature throughout the entire Northwest. Some of the shale beds are bituminous and contain thin beds of lignite. Light-gray to almost white shales are well developed locally.

The limestone strata of the Cretaceous are in most cases characterized by their peculiar chalky texture. In some localities the rock is a pure chalk, white to light gray in color, and composed almost wholly of the microscopic remains of lime-shelled Foraminifera. From the purer varieties there is every gradation to chalky shale or calcareous sandstone. Some of the limestone is hard and resistant, but in general it is much too soft for use in building. Colors observed include light blue, lavender, yellow, buff and light red. In a few places the chalky limestone beds contain concretions of flinty chert. A variety of other concretions are also observed.

The sandstone of the Cretaceous in Kansas belongs chiefly to the basal division, the Dakota. The Dakota sandstone is a coarse-grained, rather loosely cemented, massively bedded formation, gray to light or dark brown in color. As observed in many exposures it is very much cross-bedded. The chief cementing material is calcium carbonate, but iron oxide is also abundant, the content of iron being so great at some weathered exposures that the color is changed to a very dark brown and the weight of the rock is perceptibly increased. Where the rock is firmly cemented, it is very hard and resistant, but other portions of the formation are soft and crumbling. As a rule, the rock is very porous and presents most favorable conditions for the storage of underground water. Sandy beds, which occur higher in the system, as in the Carlile shale, are finer in their average texture and lighter colored than the Dakota.

ect of topography. The topography of the Cretaceous is essentially similar in many respects to that of the sylvanian and Permian area farther east. The most prom- topographic features of eastern Kansas are the series of -south escarpments formed by hard limestone members alternate with soft, easily eroded shale members. In the of Cretaceous outcrop there are also horizons which offer vely great resistance to agencies of erosion and, as in the sylvanian area, more or less prominent escarpments are d. However, the Cretaceous escarpments are in general persistent and clearly defined. The divides between ns are rather characteristically broken up into buttes and ed hills. The east margin of the Dakota sandstone is es- ly marked by rough craggy buttes. Shales areas in the ceous belt, especially that of the Pierre shale, are marked ne districts by more or less numerous symmetrical "tepee ," hill of shale capped by large concretions or other re- t portions of the rocks.

ucture. As shown by Logan,[177] and as indicated in the ure-contour map (part IV), the general dip of the Creta- formations in Kansas is to the northeast. The dip is gentle, amounting to an average of about 5 to 7 feet per and appears to be constant for considerable distances. As mined by Darton,[178] chiefly from well records, the Creta- of northwestern Kansas dips to the north and northwest, d, gentle anticline with a north-and-south-trending crest found close to the line between Decatur and Norton es. Similarly a slight anticlinal bulge is indicated in and Hodgeman counties. A more clearly defined struc- feature is found near the western border of the state, and southwest of Coolidge, Hamilton county.

nal character. The fossils of the Cretaceous are so very ent from those of other parts of the state that they may tinguished with the greatest ease. Mollusks make up than ninety per cent of all the faunas, large and small pods being the most abundant, and the coiled, rather ornamented cephalopods being the next most common. rs are extremely common in some beds, locally making ts which are composed almost wholly of their shells. A

Logan, W. N.; The Upper Cretaceous of Kansas: Kan. Univ. Geol. Survey, p. 206-215, 1897.

Darton, N. H.; Geology and Underground Water Resources of the Central ains: U. S. Geol. Survey, Prof. Paper 32, Pl. 58, p. 191, 1905.

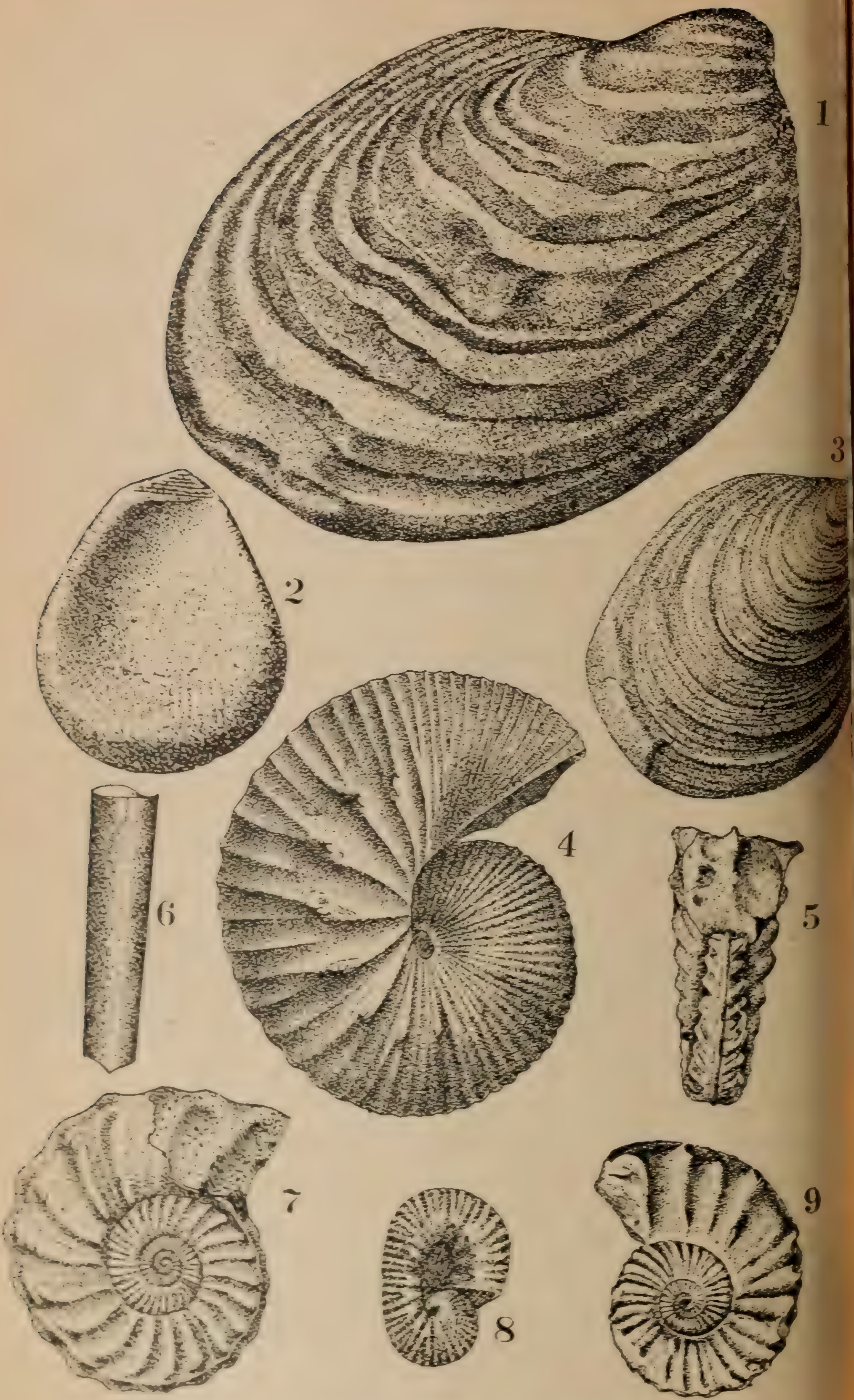

Plate IX.—Typical fossils from the Cretaceous.

er of varieties of *Inoceramus* are found, and as a whole re probably more widespread and more abundant in the eous rocks of Kansas than any other fossil. Examples mon invertebrate fossils from the Cretaceous of Kansas ustrated in plate VIII.

Cretaceous rocks of Kansas are famous all over the on account of the remarkable vertebrate fossils which een found in them, and which, largely through the studies S. W. Williston, while a member of the State Geological , have been made known. Among the most noteworthy se are the large marine reptiles, the mosasaurs, plesio- and ichthyosaurs; the flying reptiles or pterosaurs; and xtremely interesting primitive toothed birds. Many of fossils, both vertebrate and invertebrate, are at present State University of Kansas at Lawrence.

divisions. On the basis of lithologic character and fos- e strata of the Cretaceous have been divided into a num- formations and members. The classification of the as developed in Kansas agrees closely with that gen- adopted in the Great Plains province. The names used report are those which appear to belong most appro- y with the subdivisions in Kansas and which accord most with established rules of priority.

SUBDIVISION OF THE CRETACEOUS SYSTEM IN KANSAS.

Formation.	Member.
Pierre shale.	Undifferentiated.
Niobrara.	Smoky Hill chalk. Fort Hays limestone.
Benton.	Carlile shale. Greenhorn limestone. Graneros shale.
Dakota sandstone.	Undifferentiated.

ANATION OF PLATE IX. Pelecypods: *Inoceramus gilberti*, a robust, coarsely wrinkled shell, 1; *Inoceramus labiatus*, one of the commonest fossils in the s of Kansas, 3; *Ostrea congesta*, an early oyster which lived in very large num- e Cretaceous seas of Kansas, view of interior of shell, 2. Cephalopods: *Belem-* [illegible], a small, straight shell representing an early squid, broken part of a 6; *Scaphites vermiformis*, a closely coiled, ribbed ammonite of the Benton, 4 *pis woolgari*, 7; *Prionotropis hyatti*, side view 9, front view 5; *Scaphites is*, 8.

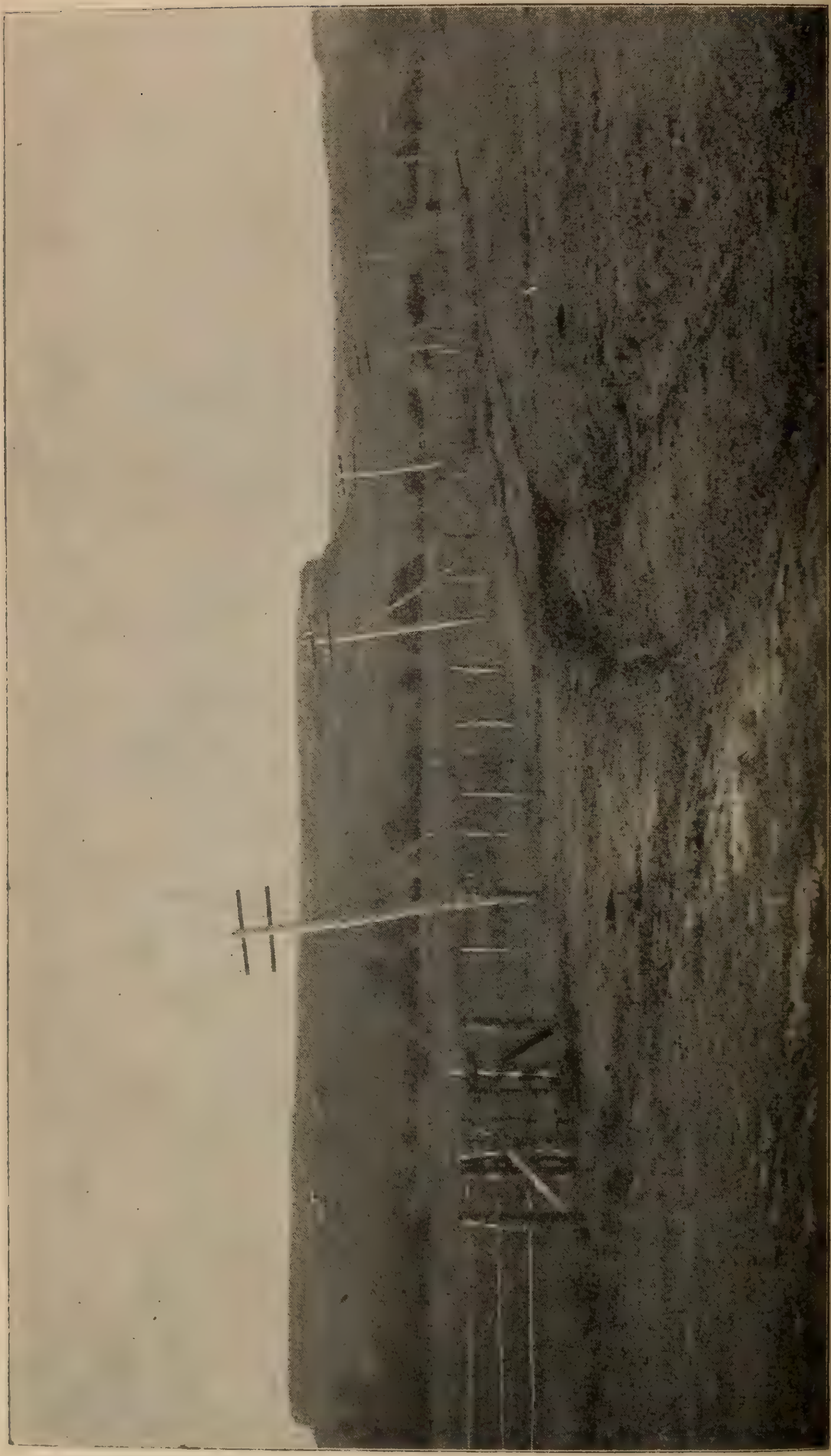

PLATE X.—Dakota sandstone bluffs in eastern Ellsworth county, about six miles west of Brookville.

Dakota Sandstone.[179]

Dakota sandstone appears at the surface in a rather but extremely irregular zone, which extends from gton county south and southwest to Arkansas river in d Barton counties, and up the Arkansas to Ford county, t disappears beneath the Tertiary deposits. The for- reappears in a number of places along Cimarron river tributaries in the extreme southwestern corner of the To the northwest the Dakota sandstone passes beneath her formations of the Cretaceous, extending, deeply far beyond the state boundaries. It is sharply up- with other sedimentary beds on the east flank of the Iountains in Colorado. (Plates II and XI.) In north- Kansas it probably lies more than 2,000 feet below face. In the northern counties the Dakota rests on k shales of the Wellington formation, to the south on ata of the Cimarron group. The equivalent of the in southwestern Kansas is found overlying the eroded hean deposits.

the Dakota is chiefly a sandstone formation, there ortant associated shale deposits at this horizon in The shale, although considerable in extent, is so in its relation to the sandstone that stratigraphic is not possible. As defined by Logan[180] from ex- observations along the outcrop of the Dakota, there are in divisions of the formation in central Kansas—a ortion, 150 feet or more thick, consisting of massive ne alternating with variously colored shale; and an ortion, 35 to 50 feet thick, containing lignite and more bundant salt and gypsum. The total thickness of the ranges from 200 to more than 300 feet.[181]

Benton Formation.[182]

Benton formation consists of shale with intercalated es and sandstones. Its outcrop is a wide belt of rather undulating country extending diagonally across the

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eek, F. B., and Hayden, F. V.; Descriptions of New Lower Silurian (Primor- ssic, Cretaceous and Tertiary Fossils, collected in Nebraska, by the exploring nder the command of Lieut. G. K. Warren, with some remarks on the rocks they were obtained: Phila. Acad. Sci., Proc., vol. 13, pp. 410, 420, 1862. Dakota City, Neb.

ogan, W. N.; loc. cit., pp. 207-209.

arton, N. H.; loc. cit., p. 152.

eek, F. B., and Hayden, F. V.; loc. cit., pp. 419, 421, 1862. Named from , Mont.

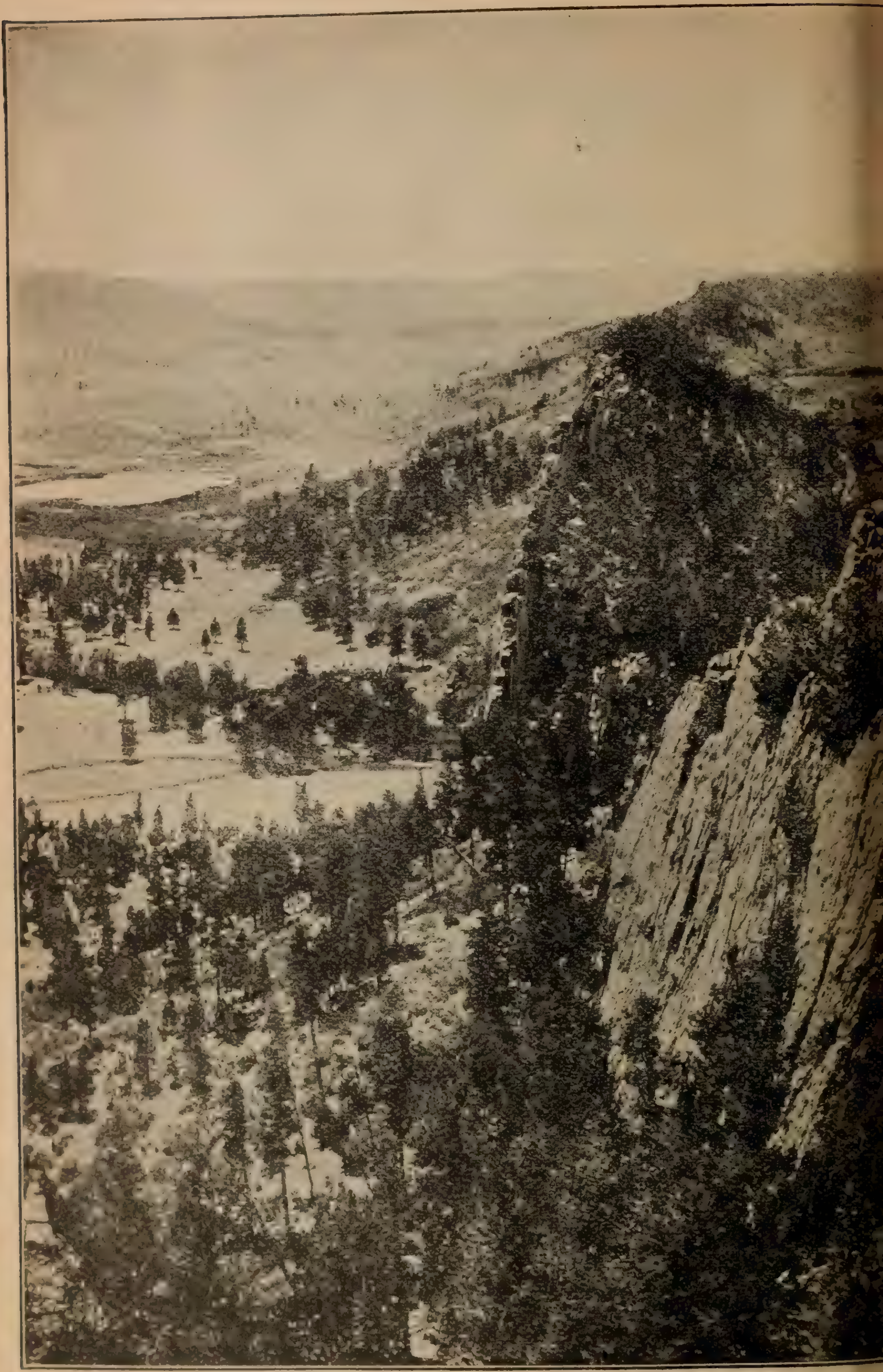

Plate XI.—Wall of Dakota sandstone west of Trinidad, Colo. Ou cropping edge of sandstone upturned on east side of Rocky Mounta uplift.

e from Republic and Washington counties at the northeast 'ord, Hodgeman and Finney counties in the southwest. e the Benton disappears beneath the Tertiary, but it re- ars along the valley of Arkansas river in Kearny and ilton counties. The thickness of the formation is some- t variable, but it averages about 400 feet.

ree main stratigraphic subdivisions are included in the on formation of Kansas—from the base upward, respec- y, the Graneros shale member, the Greenhorn limestone ber, and the Carlile shale member.

neros shale member.[183] The basal portion of the Benton lark clay shale varying in thickness from 20 to 30 feet[184] to ly 200 feet.[185] In central Kansas this member, which from sures in Colorado has been called the Graneros shale, is er bituminous, hard and slaty, and on weathering breaks thin flakes. Here it is not very thick, but in the valley rkansas river toward the western border of the state it very important division.

eenhorn limestone member.[186] The middle portion of the on formation, throughout Kansas and eastern Colorado, is osed of calcareous beds, including limy shale, soft, chalky stone, and thin beds of hard, resistant limestone. This ion, 40 to 60 feet in thickness, is termed the Greenhorn stone. The basal part of the member, about 15 feet thick ncoln marble" of Logan),[187] is made up of bluish-gray, , flinty but easily weathering limestone, in beds less than hes thick, alternating with shale. About 16 feet of white ght-cream colored, fine-grained, thin-bedded limestone agstone" horizon)[187] follows, and is overlain in turn by 40 of limy shales and thin beds of limestone filled with im- sions of the fossil shell *Inoceramus labiatus* ("Inoceramus" on).[187] The top of the Greenhorn member is marked by a um of limestone about 9 inches thick which breaks charac- tically into long, angular pieces somewhat like fence posts nce post" horizon).[187]

. Gilbert, G. K.; The Underground Waters of the Arkansas Valley in Eastern lo: U. S. Geol. Survey, 17th Ann. Rept., pt. II, p. 564, 1896. Named from os, Pueblo county, Colorado.

. Logan, W. N.; loc. cit., p. 216.

. Darton, N. H.; Guidebook of the Western United States, Part C, The Santa Fe U. S. Geol. Survey, Bull. 613, p. 44, 1915.

. Gilbert, G. K.; loc. cit., p. 564. Named from Greenhorn, Pueblo county, Colorado.

. Logan, W. N.; loc. cit., p. 216.

Carlile shale member.[188] The uppermost portion of the B
ton formation in Kansas consists almost entirely of sh
which from Colorado exposures has been called the Car
shale member. The lower portion of the shale, about 100
150 feet in thickness, is a soft clay shale, dark bluish gray
color. It contains occasional thin beds of limestone and is v
fossiliferous, containing especially enormous numbers of fo
oysters ("Ostrea shales").[189] The upper part of the Car
member is an unfossiliferous, loose-textured blue-gray sh
characterized by the occurrence in its upper portion of
merous concretions. The concretions are lens-shaped, and v
in size up to 4 or 5 feet in diameter. They are dark colo
and are solid carbonate of lime or hollow geodes lined w
calcite crystals.

Niobrara Formation.[190]

The Niobrara formation, comprising the main calcare
portion of the Cretaceous system in Kansas, underlies the
tire northwestern part of the state. Its outcrop is a wide a
trending southwest from Jewell county to Finney cou
marked at its eastern margin by a series of slopes which
above the rolling topography of the Benton formation. To
west the Niobrara is thickly covered by deposits of Terti
age, but along the larger streams, notably Smoky Hill ri
the Tertiary has been cut away, making extensive exposu
of the subjacent Niobrara. The thickness of the Niobr
formation ranges from about 350 feet[191] to 650 feet,[192]
average being somewhat nearer the lower figure. On litholo
as well as faunal grounds, a division of the Niobrara for
tion is made in Kansas.

Fort Hays limestone member.[193] The lower portion of
Niobrara, having an average thickness of 50 feet, is the F
Hays limestone member. The limestone is a soft, mass
light-colored rock, sufficiently resistant to erosion to weat
out in bluffs of some prominence. In well borings, it is

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[188] Gilbert, G. K.; loc. cit., p. 565. Named from Carlile, Pueblo county, Colo

[189] Logan, W. N.; The Upper Cretaceous of Kansas: Kan. Univ. Geol. Su
vol. 2, pp. 220, 221, pl. 27, 1897.

[190] Meek, F. B., and Hayden, F. V.; loc. cit., pp. 419, 422. Named from Nio
river, Nebraska.

[191] Logan, W. N.; ibid.

[192] Darton, N. H., The Geology and Underground Water Resources of the Ce
Great Plains: U. S. Geol. Survey, Prof. Paper 32, p. 155, 1905.

[193] Mudge, B. F.; Notes on the Tertiary and Cretaceous Periods of Kansas:
Geol. and Geog. Survey of Terr., Bull., vol. 2, pp. 218-221, 1876. Named from
former Fort Hays, Ellis county, Kansas.

ished in most cases from associated members by its er hardness. The outcrop of the Fort Hays limestone)er extends along the margin of the Niobrara area from l county to Finney county and up Smoky Hill river into county. It is also observed in central Hamilton county of Coolidge and at other points north of Arkansas river.

oky Hill chalk member.[194] The upper division of the Nio-, termed the Smoky Hill chalk member, comprises much iicker portion of the formation, having a total thickness ng from 300 to 350 feet. In an unweathered condition ıalk is a massive, light bluish-gray, clayey rock, but on ıering the color changes to yellow or buff, or in some light red on account of the oxidation of iron contained in eposit. Surface waters serve to leach out the oxidized and other coloring matter in many places, leaving the rock bleached and white. In well borings the member ap- in most cases as a pale-blue chalky clay, which is only ly sticky when wet. Some rather pure chalk is found y in the Smoky Hill member, as near Norton. The best ures of the chalk are found in the valley of Smoky Hill where prominent buttes and castellated cliffs mark the)p.

Pierre Shale.[195]

e northwest counties of Kansas are underlain by the e shale, the uppermost division of the Cretaceous in this n. The Pierre is covered by deposits of Tertiary for the est part, but outcrops appear in Cheyenne county, along er and Sappa creeks in Rawlins and Decatur counties; on ie Dog creek, southwest of Norton county, and over a large ın Smoky Hill river and tributaries in Wallace and Logan ies. The shale is somber, dark bluish-gray in color, but ıers to a brownish tint. The formation is soft and clayey, ng readily to agencies of erosion. Some beds contain r numerous lens-shaped concretions which contain dis-ve marine fossils. The maximum thickness of the Pierre in Kansas is not more than 200 feet.[196]

Cragin, F. W.; On the Stratigraphy of the Platte Series, or Upper Cretaceous Plains: Colo. Coll. Studies, vol. 6, p. 51, 1896. Named from Smoky Hill river.

. Meek, F. B., and Hayden, F. V.: loc. cit., pp. 419, 424. Named from Fort Now Pierre, S. Dak.

Logan, W. N.: loc. cit., p. 221.

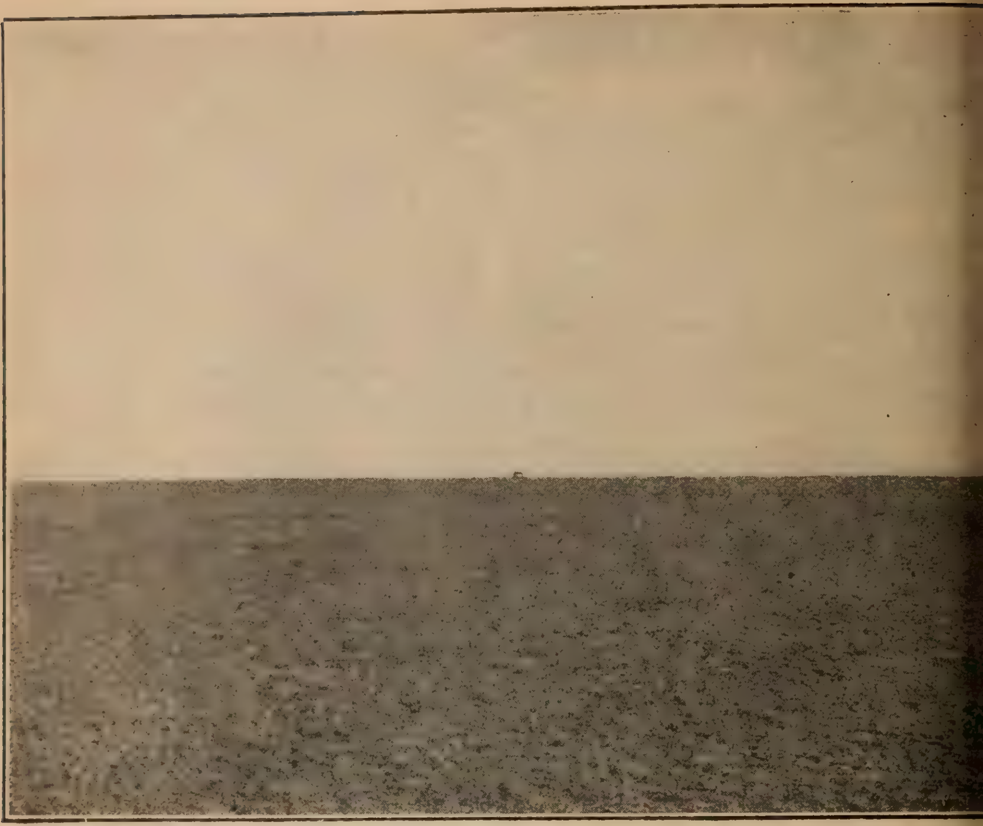

Plate XII.—The Great Plains of western Kansas, smooth and alm level, sloping gently upward toward the west. In country like there is no surface evidence whatever of underground structure.

TERTIARY AND LATER DEPOSITS.

The greatest part of western Kansas, comprising an a thousands of square miles in extent, is covered by a mantle sand, gravel and limy clay which appears to have been posited in late Tertiary time. This widespread Tertiary posit forms the capping of the so-called high plains, and tends for great distances over eastern Colorado and weste Kansas and Nebraska. The name Ogalalla formation, fron locality in southwestern Nebraska, has been adopted for t portion of the Tertiary.[197]

Ogalalla Formation.

The Ogalalla formation, as indicated by present field vestigations, occupies all of the high plains (plate XII) western Kansas. Its eastern boundary is a very irregular l nding southwestward from Jewell county to Finney county, nce eastward to Reno county, where it turns again to the ithwest into Clark and Meade counties. The formation exids farthest east along the divides between the main streams. e larger rivers have cut through the Tertiary and carried ay the sand and gravel from large areas. In some instances, tably the valley of Smoky Hill river, the Ogalalla has been noved for long distances; but in others, as along Cimarron er and tributaries in southwestern Kansas, it has been cut ay only locally (plate XXII).

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[197] Darton, N. H.; Preliminary Report on the Geology and Water Resource Nebraska West of the One Hundred and Third Meridian: U. S. Geol. Survey, 19th A Rept., pt. IV, p. 734, 1898. Named from Ogalalla, Keith county, Nebraska.

The materials of the Ogalalla formation are mainly sands, ivelly sands and gravels more or less cemented by carbonate lime into a grit rock which in many cases has the appearce of rough mortar. On account of this resemblance, the me "mortar beds" has been rather widely applied to porns of the Kansas Tertiary.[198] The deposits are in general careous, in some cases consisting mainly of lime carbonate l containing but little sand. In places, the formation is a ht colored sandy clay containing much carbonate of lime in eaks or nodules. The gravels found in the Ogalalla forman and derived by its weathering contain pebbles varying in e from 4 to 5 inches in diameter to coarse sand. They are nposed of granite, syenite, porphyry, basalt and other igous rocks and are evidently derived from areas of crystalline ks to the west. Quartz pebbles are common. The sand merely the finer material derived from the weathering of ieous rocks, but is largely a pure quartz sand. It exhibits rious degrees of fineness, but when examined closely the iins are in almost all cases well-rounded. Accumulations of all pockets of black magnetite sand are not uncommon in ny parts of the Ogalalla.[199] Clay beds are commonly white pinkish and in some places form low steep banks or cliffs ng the headwaters of streams. In a few localities, especially rton and Phillips counties, beds of volcanic ash a number of t in thickness occur. They are evidently related to similar posits which have been found over a considerable area in braska[200] and Oklahoma.[201] Volcanic ash does not constie an important part of the Kansas Tertiary deposits.

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[198] Haworth, Erasmus; Physiography of Western Kansas: Kan. Univ. Geol. vey, vol. 2, pp. 22, 25, 32, etc., 1897. Physical Properties of the Tertiary: loc. cit., 258-260.

[199] Haworth, Erasmus; Physical Properties of the Tertiary: Kan. Univ. Geol. vey, vol. 2, p. 255, 1897.

[200] Darton, N. H.; loc. cit., pp. 760, 761.

[201] Buttram, Frank; Volcanic Dust in Oklahoma: Okla. Geol. Survey, Bull. 13, pp., 1914.

The thickness of the Ogalalla formation in Kansas varie from practically nothing to more than 300 feet. Throughou the largest part of western Kansas it averages from 150 t 200 feet. In general the records of wells which have bee drilled through the formation indicate that the greatest thicknesses are found on broad flat divides which have been littl affected by erosion.

There are no well-defined stratigraphic horizons in th Kansas Tertiary which can be traced over considerable area in an investigation of the structure of these beds. Prominen "mortar beds," which are well developed in some regions, cannot be traced with sufficient accuracy or to a sufficient distance to be of great service. Also, these distinctive portion of the Tertiary are found at the base, in the middle or at th summit of the formations in different localities. Since, however, a very large portion of the area underlain by the Ogalall is an almost featureless plain, it is in general very difficult t determine in any satisfactory way the structural relations o the Tertiary.

Numerous remains which have been found in the Ogalall formation in Kansas, indicate that it should be referred to th Pliocene epoch of Tertiary time, and the deposits are so correlated by Darton,[202] but it is possible that at least in part th beds are upper Miocene in age.

Quaternary Deposits.

Deposits made during the Glacial epoch and in recent geologic time are found in various parts of the state. They ar of importance to the petroleum geologist and producer becaus of their relations to the underlying consolidated strata, whic must be studied carefully in any scientific exploration for o or gas. In some cases these deposits only partially obscur the structure of the subjacent rocks, but in others they conceal it entirely. The deposits in Kansas which are referred t the Quaternary (plate XIII) include (*a*) glacial deposits, (*b* Pleistocene river deposits, (*c*) loess, (*d*) alluvium, and (*e* sand hills.

(*a*) *Glacial deposits.* The former existence of a large glacier which advanced from the north and covered a large are

---

[202] Darton, N. H.; Geology and Underground Water Resurces of the Central Gre Plains: U. S. Geol. Survey, Prof. Paper 32, p. 150, 1905.

e northeastern portion of the state is evidenced by wide-
ad deposits of glacial drift, bowlders and other glacial
rials which entirely cover the region north of Kansas
and east of Washington and Riley counties (plate XIII).
glacial drift is a heterogeneous mixture of clay, sand,
les and bowlders which is found on the hilltops as well as
e valleys. The drift was deposited beneath and at the
in of the "Kansas ice sheet," one of the earliest of the
nental glaciers which during the Pleistocene covered
nous areas in the United States. The drift is very much
hered and thoroughly oxidized, so that the color due to
ron oxide content is in most cases a rich brown or red
he pebbles and bowlders are decayed and soft. Sufficient
has elapsed since the glaciation of northeastern Kansas
rmit considerable stream erosion. Lakes and swamps
h are so numerous in recently glaciated districts are there-
absent, and the general appearance of the country re-
les somewhat non-glaciated portions of the state. In
places, the drift and other deposits made by the glacier
been removed by erosion, exposing the underlying hard
strata, but for the greater part, the mantle of glacial
rial effectually covers the underlying bed rock and ob-
s its structure. Lake deposits of glacial origin have been
ified by Professor Todd at various points along the mar-
f the Kansas glacier. The thickness of the glacial drift
the average not greater than 6 to 10 feet, and in many
s it is practically absent, but locally, as shown by well-
gs, there are accumulations of more than 60 feet.[203]

) *Pleistocene river deposits.* During the Pleistocene,
lacial period, considerable deposits of sand, sandy clay
lluvium were made in various stream valleys of the state.
me cases the material deposited may have been derived
the continental glacier to the north, but in large part
deposits were evidently obtained by normal erosion
sses from the drainage basins of the streams themselves.
nsive deposits of this sort are found along the course of
nsas river, Kansas river and tributaries.

e of the most interesting of the river deposits of Pleisto-
time in Kansas is found in McPherson, Marion, Harvey
Reno counties (plate XIII). This deposit, which has been

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3. Personal communication from Prof. J. E. Todd.

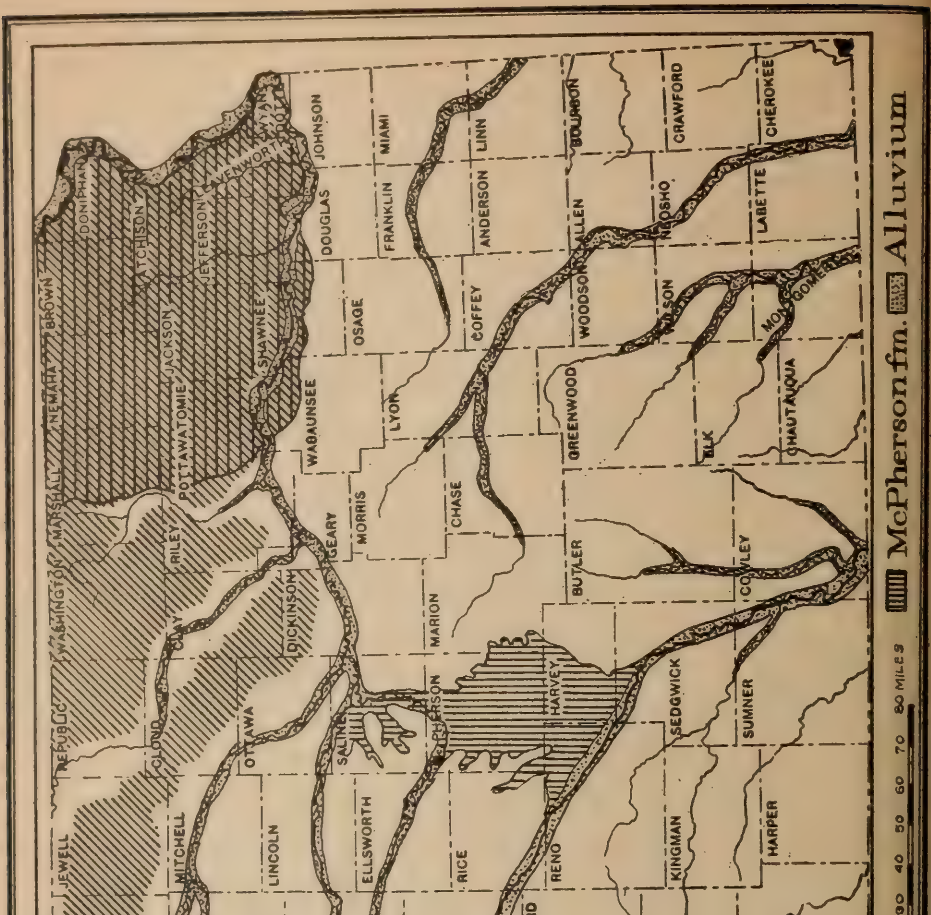

PLATE XIII.—Outline map showing distribution of the Quaternary deposits of Kansas.

the McPherson formation,[204] is found in a broad channel, in the upper Permian shales and the Dakota sandstone, tending from Smoky Hill river at the north to Arkansas n Sedgwick county. The area covered comprises prac- the entire eastern half of McPherson county south of drawn from Lindsborg to Canton, all of Harvey county f Newton and most of eastern Reno county. The ma- composing the deposit consists of irregular layers of clay and gravel, cemented loosely by carbonate of lime. nd and gravel contain an abundance of water, and sup- e water plants of neighboring cities. The thickness of mation varies from a few feet to more than 100 feet.

Loess. Covering a wide area of the High Plains be- the valleys of northern and northwestern Kansas is a -surfaced, thick mantle of loess (plate XIII). Accord- Darton,[205] the border of the loess-covered area trends rd from Greeley county to Ellis county, thence north- o Osborne county and northeastward to Republic and ngton counties. There are also thick deposits of loess hout northeastern Kansas in the district covered by the drift. There are no sharp boundaries to the region of eposits because of the presence of the loess only on the ed uplands. In the west in few cases does it exceed a ess of 30 to 40 feet, and on the average it is very much it in the northeastern counties of the state the thickness eneral much greater and in some places near Missouri he loess is more than 100 feet thick.

Alluvium. There are many wide valleys in Kansas are filled to various depths with deposits of alluvial mate- ought down by the streams. The largest and most ex- of these river deposits is that along the Arkansas river which has a width of 6 to 10 miles and crosses a con- ble part of the state. Other large streams, such as Kan- er and its tributaries to the west, Republican, Solomon, and Smoky Hill rivers, have wide flood-plains composed r-made alluvium. All the river and creek valleys contain or less alluvial material of relatively recent origin, and f the lower slopes of hills are covered by talus and slope-

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Haworth, Erasmus, and Beede, J. W.; The McPherson Equus Beds: Kan. ol. Survey, vol. 2, pp. 287-296, 1897. Named from McPherson, McPherson ansas.

Darton, N. H.; The Geology and Underground Water Resources of the Central ains: U. S. Geol. Survey, Prof. Paper 32, pl. 44, 1905.

wash derived from recent weathering. The deposits, which a
mainly sands and loams intermixed locally with gravel, are i
portant to the petroleum producer because of their widespre
covering of rock outcrops. An excellent example is found
the Walnut river valley in southern Butler county. Some of t
most productive wells and valuable leases in this district a
located on the wide river bottom where there are no rock e
posures and practically no indication from surface evidence
the anticlinal structure of the rocks underground which co
trols the accumulation of the oil.

(*e*) *Sand dunes.* A wide area in central Kansas, chiefly
the south side of Arkansas river, from Ford to Reno counties,
occupied by wind-blown sand. The sand constitutes hills a
ridges of moderate height, with iregular basins and flats inte
vening. The sand has been derived chiefly from the alluv
flats along Arkansas river, being blown out by the winds, whi
are prevailingly from the northwest. Indirectly, much of t
sand comes from the weathering of the Dakota sandstone a
Tertiary deposits in the region. The dune sand effectua
covers the bed rock and makes impossible any determination
the rock structure from surface evidence. The area occupi
by the sand, therefore, can be prospected only by "wild-ca
methods.

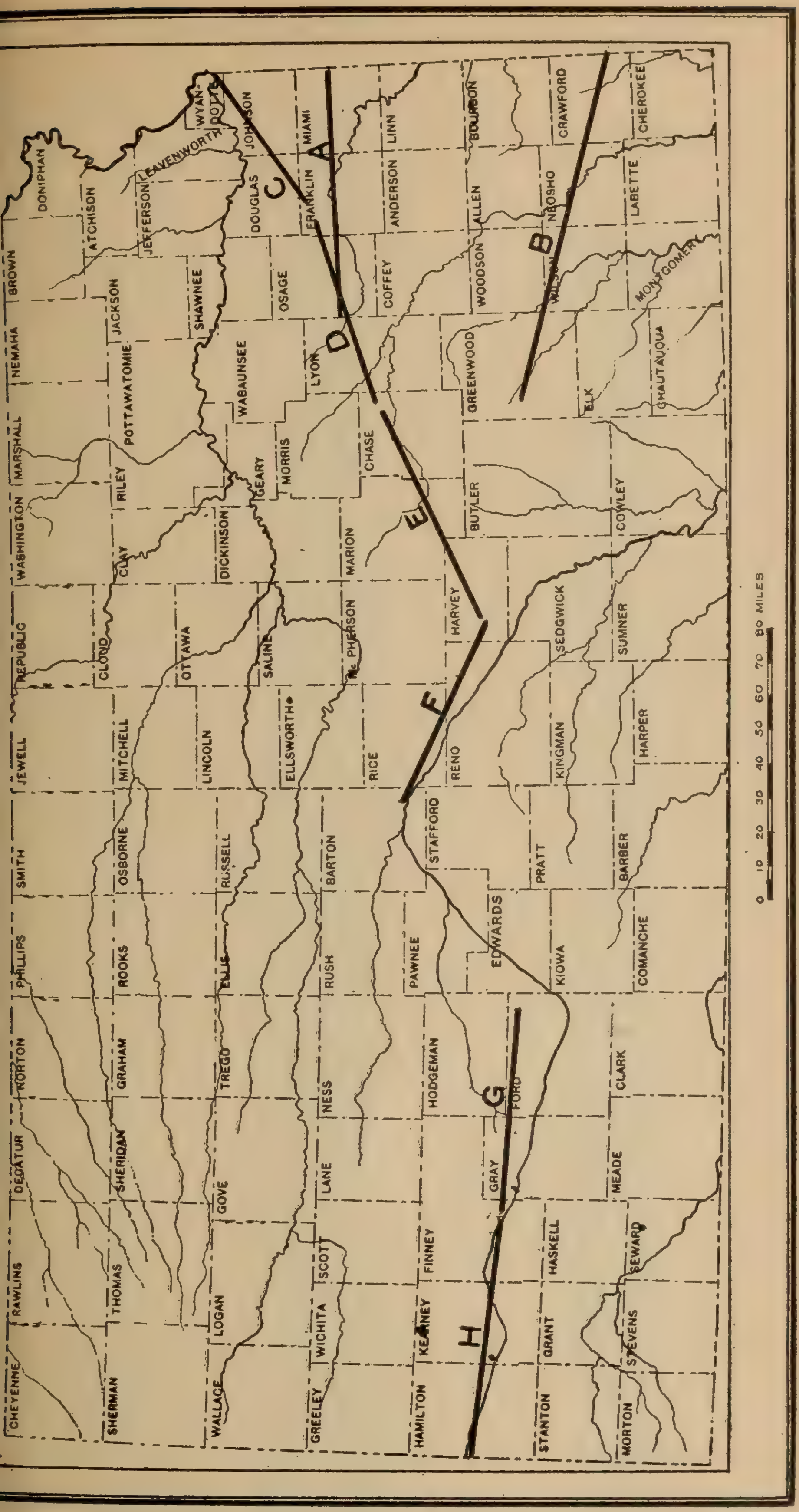


PLATE XIV.—Map showing location of geological sections *A* to *H*, plates XV to XVII.

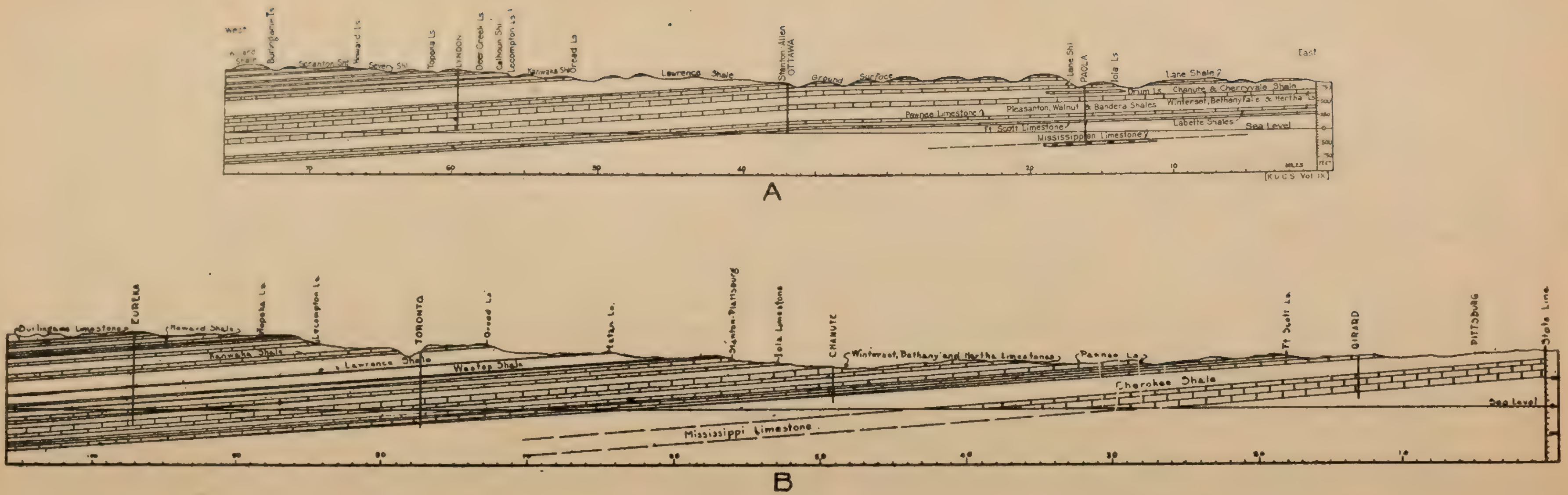


PLATE XV.

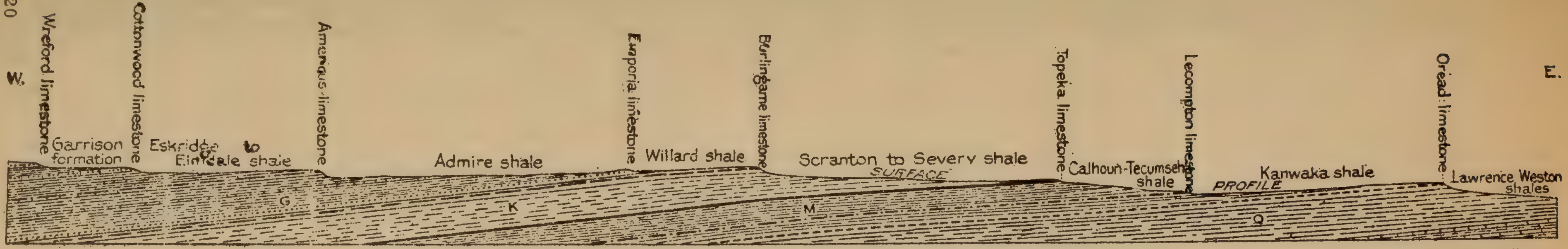
A. Section showing underground relations of rocks from the state line east of Paola to a point ten miles west of Osage City.

B. Section showing underground relations of rocks from the state line east of Fort Scott to Burlington.

Vertical scale greatly exaggerated, which has the effect of increasing the apparent tilt of the beds.

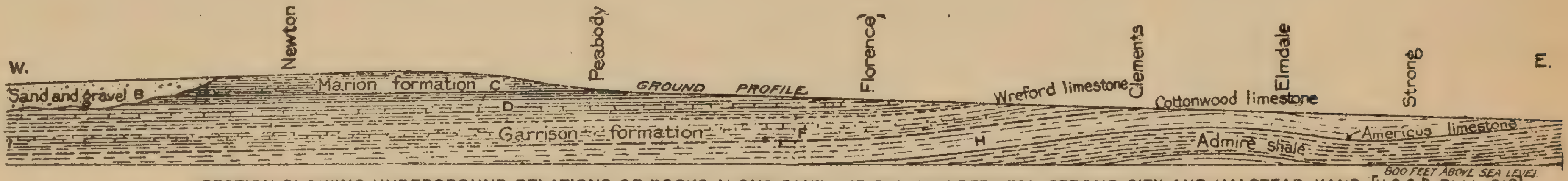
SECTION FROM KANSAS CITY THROUGH OLATHE AND BALDWIN ALONG LINE OF OLD SANTA FE TRAIL. [U.S.G.S. BL. 613]

C



SECTION SHOWING RELATIONS OF LIMESTONES AND SHALES ACROSS THE SOUTHERN PART OF THE AREA COVERED BY SHEET 2 [U.S.G.S. BULL. 613]
VERTICAL SCALE GREATLY EXAGGERATED (26 TIMES). THIS HAS EFFECT OF INCREASING APPARENT TILT OF BEDS

D

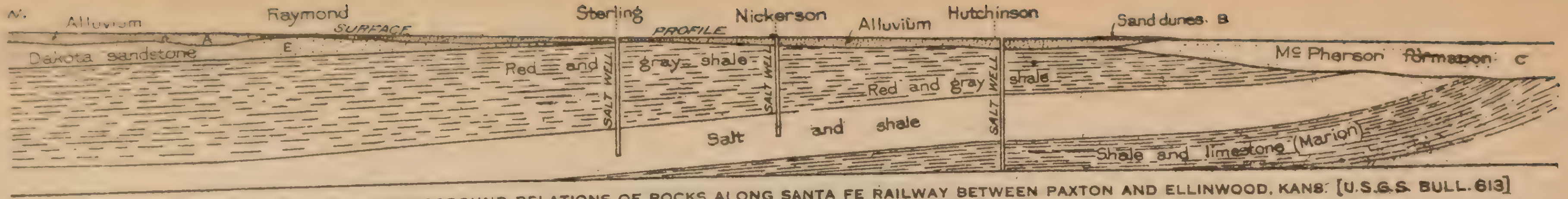


SECTION SHOWING UNDERGROUND RELATIONS OF ROCKS ALONG SANTA FE RAILWAY BETWEEN STRONG CITY AND HALSTEAD KANS [U.S.G.S. BULL. 613]
VERTICAL SCALE GREATLY EXAGGERATED (26 TIMES). THIS HAS EFFECT OF INCREASING APPARENT TILT OF BEDS

E

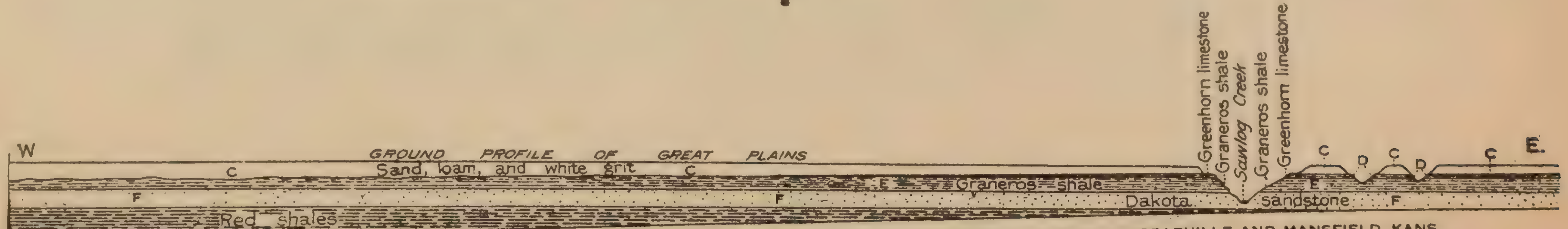
PLATE XVI.

C. Section from Kansas City through Olathe and Baldwin along the line of the old Santa Fe trail.
D. Section from Pomona to point west of Emporia.
E. Section from Strong City to Halstead.



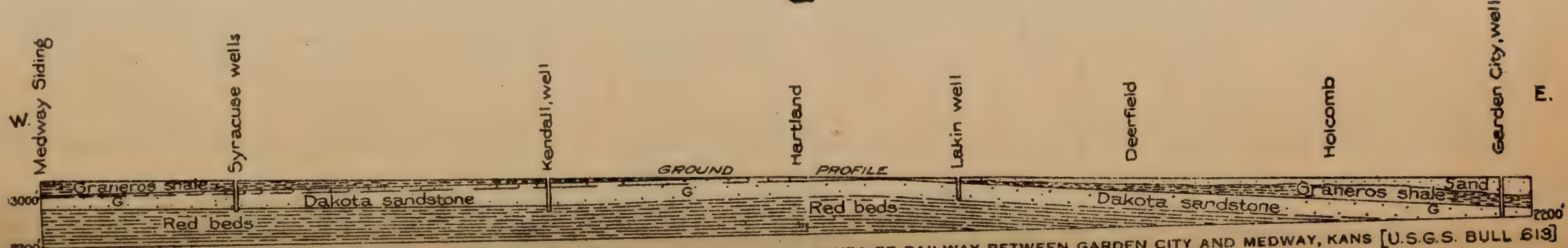
SECTION SHOWING UNDERGROUND RELATIONS OF ROCKS ALONG SANTA FE RAILWAY BETWEEN PAXTON AND ELLINWOOD, KANS. [U.S.G.S. BULL. 613]
VERTICAL SCALE GREATLY EXAGGERATED THIS HAS EFFECT OF INCREASING APPARENT TILT OF BEDS

F



SECTION SHOWING UNDERGROUND RELATIONS OF ROCKS IN PLATEAU NORTH OF ARKANSAS RIVER BETWEEN SPEARVILLE AND MANSFIELD, KANS [U.S.G.S BULL. 613]
VERTICAL SCALE GREATLY EXAGGERATED. THIS HAS EFFECT OF INCREASING APPARENT TILT OF BEDS

G



SECTION SHOWING UNDERGROUND RELATIONS OF ROCKS ALONG SANTA FE RAILWAY BETWEEN GARDEN CITY AND MEDWAY, KANS [U.S.G.S. BULL 613]

H

PLATE XVII.

F. Section from Paxton to Ellinwood.

Glen M Bailey

36

STATE GEOLOGICAL SURVEY *of* KANSAS
RAYMOND C. MOORE, State Geologist

OIL *and* GAS RESOURCES *of* KANSAS

PART V

ALLEN AND NEOSHO COUNTIES

By RAYMOND C. MOORE AND
EMMETT R. ELLEDGE

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BULLETIN 6

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State Geologist
RAYMOND C. MOORE,

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Raymond C. Moore, Ph. D.,
State Geologist.

CONTENTS.

PA

Oil and Gas Resources of Allen and Neosho counties
- Introduction
  - Location
  - Topography and drainage
  - Culture
  - Acknowledgments

History of oil and gas development

Geology
- Surface formations
- Structure
- Subsurface geology

Oil and gas production
- General statement
- The Iola field
- The Moran field
- The Humboldt field
- The Chanute field
- The Erie field
- Other fields
- Refineries

ILLUSTRATIONS.

PLATE I. Geological map of Allen and Neosho counties
II. Geological section across Allen county
III. Geological section across Neosho county
IV. Production map of Allen and Neosho counties

FIGURE 1. Location map of Allen and Neosho counties
2. Diagram showing irregular sand conditions in wells east of Chanute

HE OIL AND GAS RESOURCES OF ALLEN AND NEOSHO COUNTIES, KANSAS.

By Raymond C. Moore and Emmett R. Elledge.

INTRODUCTION.

ocation. Allen and Neosho counties are situated in the heastern portion of Kansas, separated by the width of a le county both from the east and south boundaries of the e (figure 1). Together they form a rectangle about 23 s in an east-west direction, by 45 miles in a north-south di- on. The combined area of the counties is about 1,080

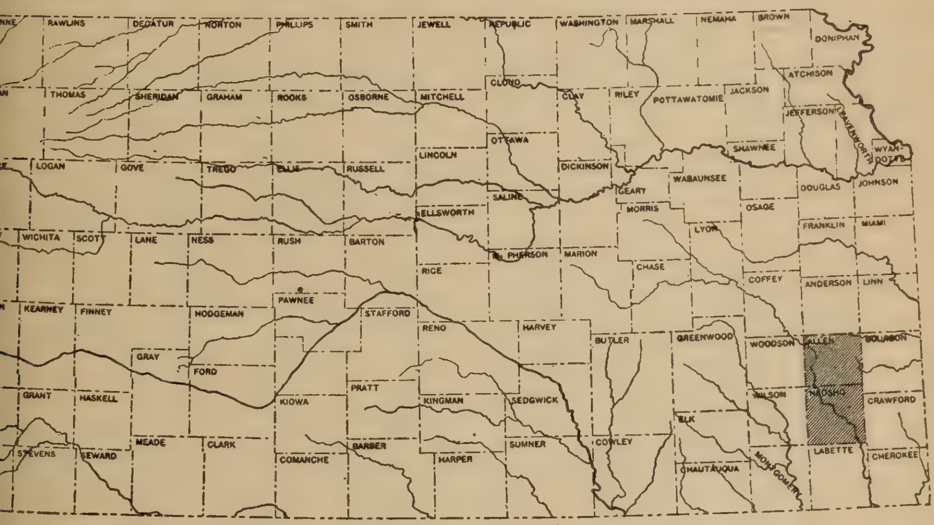

FIGURE 1.—Location map of Allen and Neosho counties.

ire miles. Owing to the similar conditions existing in n and Neosho counties, they may conveniently be discussed ther.

opography and drainage. Allen and Neosho counties lie in the area of scarped plains which extends throughout t of eastern Kansas and a large portion of adjoining states. country is a rolling plain, the chief features of which are east-facing escarpments which are formed by the harder strata and the more or less broad river valleys which have n carved beneath the general level of the region. The rpments may be traced across the counties in very irregu- lines which trend in a general southwest-northeast direc- . Some of them, as locally that of the Iola and of the Drum limestones, are very prominent. Others are less well defined and in places grade into nearly flat or gently rolling topography in which the outcrops of the harder rocks cannot easily be traced. Above the escarpments there are commonly areas of nearly level or slightly west-sloping country which are formed by the hard beds which are gently inclined to the west, just beneath the surface. Such a prominent dip slope is that above the Iola limestone east of Humboldt and southeast of Iola. The larger streams have flat-bottomed, alluvium-filled valleys varying in width from one to three or four miles, the sides in many places bordered by steep bluffs 100 to 200 feet high.

The largest stream in the area is Neosho river, which flows south across the extreme western portion of Allen county, and from northwest to southeast across the central portion of Neosho county. Almost all of the secondary drainage of the two counties is tributary to the Neosho. Streams in the northeast corner of Allen county flow eastward into Osage river, and in southwestern Neosho county into the Verdigris.

Culture. Allen and Neosho counties contain much fertile farm land and important industrial centers. The area is therefore comparatively thickly settled. The most important towns are, in Allen county, Iola, Moran and Humboldt; in Neosho county, Chanute and Erie. Large cement and brick plants are located at Iola. Chanute contains two refineries and is an important railroad point. To the development of oil and gas in this region much of the prosperity of all the towns in the district is due.

Intersecting lines of three railroad systems, the Atchison, Topeka & Santa Fe, Missouri Pacific, and Missouri, Kansas & Texas cross Allen and Neosho counties from north to south and east to west, so that almost all parts of the oil and gas fields are readily in touch with excellent railroad facilities. A network of good automobile and wagon roads extends over all parts of the counties and is easily traversible except locally along some of the escarpments and after heavy rains.

Acknowledgments. The survey is indebted to the Empire Fuel and Gas Company for reference to their geological outcrop maps of this area and for the use of a number of measured stratigraphic sections. The account of early development in and Neosho counties is mainly drawn from Haworth's t on the oil and gas resources of Kansas, published in *

HISTORY OF OIL AND GAS DEVELOPMENT.

e first discovery of gas in the area under consideration at Iola, in 1873, when the Acers well was drilled. A er of wells were drilled in the vicinity of Iola a short time and a sufficiently large gas field was developed to supply e needs of the town. On account of the abundant supply is fuel, which has been produced from the Iola field in ıst twenty-five years, a number of important industries been located at Iola.

e first active prospecting in the vicinity of Humboldt was 94 and 1895, when Guffey and Galey drilled a number of north and south of the town. These wells found a con- able amount of gas and some oil. The Humboldt field has een so important as a gas producer as that near Iola, but yielded much more oil.

lls were drilled by Guffey and Galey in the vicinity of ute in 1894, but they were dry and the territory was for e abandoned. Later the city of Chanute drilled wells 1 found a good supply of gas, and in a short time more sufficient gas to supply the town was developed. In 1899 cessful attempt to find oil near Chanute began the oil pro- on of the Chanute field. This area has been an important 1 the oil production of Kansas.

e development of oil and gas in other parts of Allen and ho counties has followed the initial discoveries in the fields mentioned. Good production has been obtained much of the two counties and, though the oil and gas of the older fields has declined in recent years, new pro- ve areas have been found. It is apparent from tests 1 are now being made that not only may new production und in undeveloped portions of the counties, but deeper ng in parts of the old fields may yield important results. 1 500 to 700 new oil wells have been brought in each year 1915.

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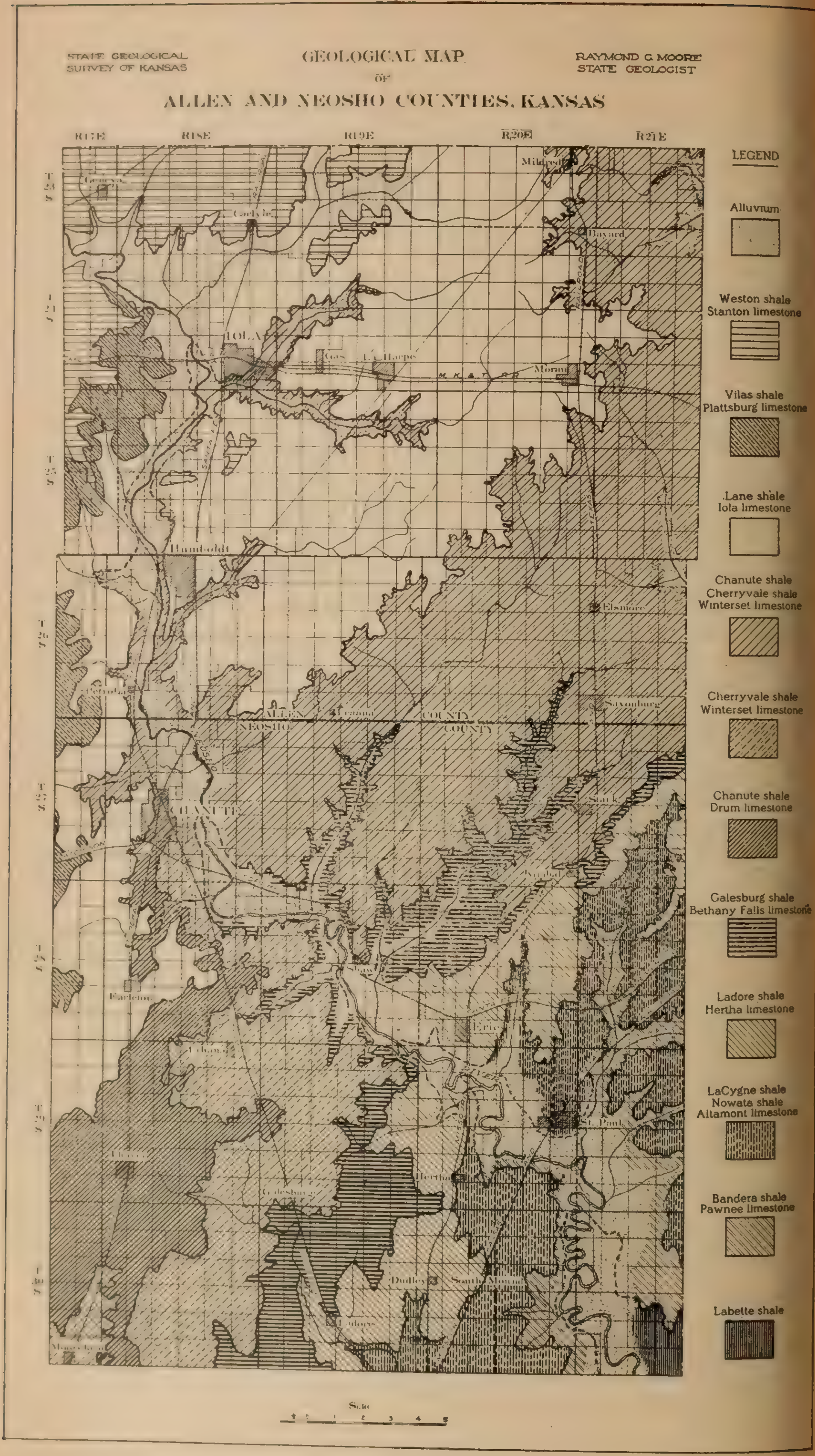
aworth, Erasmus, Special Report on Oil and Gas; Kan. Univ. Geol. Survey, vol. , pp. 29-35.


STATE GEOLOGICAL SURVEY OF KANSAS
GEOLOGICAL MAP OF ALLEN AND NEOSHO COUNTIES, KANSAS
RAYMOND C. MOORE STATE GEOLOGIST
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Mildred
Bayard
IOLA
Gas
La Harpe
Moran
Humboldt
Elsmore
Petrolia
Savonburg
ALLEN COUNTY
NEOSHO COUNTY
CHANUTE
Stark
Kimball
Earlton
Erie
Urbana
St. Paul
Thayer
Galesburg
Hertha
Dudley
South Mound
Ladore
LEGEND
Alluvium
Weston shale Stanton limestone
Vilas shale Plattsburg limestone
Lane shale Iola limestone
Chanute shale Cherryvale shale Winterset limestone
Cherryvale shale Winterset limestone
Chanute shale Drum limestone
Galesburg shale Bethany Falls limestone
Ladore shale Hertha limestone
LaCygne shale Nowata shale Altamont limestone
Bandera shale Pawnee limestone
Labette shale
Scale
1 0 1 2 3 4 5

PLATE I.

GEOLOGY.

face formations. The rocks of Allen and Neosho coun-
long to the middle portion of the Pennsylvanian system.
consist of alternating beds of limestone and shale, and
of some sandstone. The limestones form more or less
nent escarpments which cross the area in a general di-
ı from northeast to southwest. On account of the ero-
f Neosho river and its tributaries the outcrop of the
tions, and consequently the position of the escarpments,
emely irregular (see geologic map, plate I). The shales,
are very readily weathered, form the slopes beneath the
one escarpments and much of the gentle rolling country
f the limestone outcrops.

geologic divisions which are exposed at the surface in
and Neosho counties are the Marmaton, Kansas City,
ıg and part of the Douglas formations. The relation of
divisions to other parts of the Pennsylvanian in Kansas
ıe members of which they are composed, are shown in
ole on page 10. The divisions are arranged in the order
ch they appear geologically, the lower formations below
e upper, above.

Marmaton formation outcrops in the southeastern por-
Neosho county. The Kansas City formation, which lies
ıbove the Marmaton, may be traced from southern
o county northward along the valley of Neosho river as
Iola in Allen county and northeastward across all of
rn and eastern Allen county. It is much the most wide-
l of the formations in Neosho county. The Kansas City
tion is mainly characterized by the abundance of lime-
beds, and the area in which it constitutes the surface
tion is essentially a limestone country. The Hertha lime-
at its base forms a prominent escarpment in southeastern
o county, crossing Neosho river near the town of Erie.
clearly defined escarpments are those of the Drum and
mestone members, the former in western Neosho and
astern Allen counties, the latter west of Thayer and
ıte in Neosho county, and northward on either side of
o river in Allen county as far as Iola, and northeastward
a point south of Humboldt to Moran and the northeast
of the county. The Lansing formation occupies a small
vest of the Iola escarpment in western Neosho county and

Table showing geological divisions of Allen and Neosho counties, and their relation to other rock formations of Kansas.

- Quaternary.
  - Recent.
    - Alluvium (includes deposits along streams in Allen and Neosho counties).
  - Pleistocene.
    - Glacial deposits (northeastern Kansas).
- Tertiary (western Kansas).
- Cretaceous (western and north-central Kansas).
- Comanchean (south-central Kansas).
- Permian (central Kansas).
- Pennsylvanian (eastern Kansas).
  - Missouri group.
    - Wabaunsee formation.
    - Shawnee formation.
    - Douglas formation.
      - Oread limestone.
      - Lawrence shale.
      - Iatan limestone.
      - Weston shale.
    - Lansing formation.
      - Stanton limestone.
      - Vilas shale.
      - Plattsburg limestone.
      - Lane shale.
    - Kansas City formation.
      - Iola limestone.
      - Chanute shale.
      - Drum limestone.
      - Cherryvale shale.
      - Winterset limestone.
      - Galesburg shale.
      - Bethany Falls limestone.
      - Ladore shale.
      - Hertha limestone.
    - Marmaton formation.
      - La Cygne shale.
      - Lenapah limestone.
      - Nowata shale.
      - Altamont limestone.
      - Bandera shale.
      - Pawnee limestone.
      - Labette shale.

        } Exposed in Allen and Neosho counties.
      - Fort Scott limestone.
    - Cherokee shale.
  - Mississippian.
  - Devonian and Silurian?
  - Ordovician.
  - Cambrian.
  - Pre-Cambrian.

    } Not exposed in Kansas.

e portion of northwestern Allen county. Its most prom-member is the Stanton limestone, which forms an escarp-along the west line of Allen county. Unimportant out-representing the lower part of the Douglas formation above the Stanton in the extreme west and northwest of Allen county.

table on page 12 shows the thickness of the geologic di-s in various parts of Allen and Neosho counties observed logists of the Empire Fuel and Gas Company.

cture. The general dip of the rock strata in Allen and o counties is to the west and northwest, at the rate of 12 to 15 feet to the mile. The State Geological Survey t yet been able to make a detailed examination of the ure in this area, but it is known that there are a number ht variations from normal west or northwest dip. How-he production of oil and gas in these counties does not r to be governed wholly by the structure of the rocks in they are found. As in other parts of the mid-continent t is very desirable in drilling test wells to secure as favor-cation with reference to structure as possible. Hence ery desirable to have accurate structural maps of the area. Plates II and III show the general character of ck strata beneath the surface in Allen and Neosho coun-represented by typical well logs.

surface geology. The character of the formations be-the surface in the area under consideration is very im-t to the prospector for oil and gas and the producer. resence, extent and lithologic nature of porous beds be-the surface, which may serve as a reservoir for oil or re subjects of chief interest. Information concerning is available in part from a study of the outcrop of the tions which in these counties are buried, and in part data secured from drill records. The general character buried formations may be inferred from their charac-s seen at the outcrop, but since the outcrop is in some ces many miles distant from the area, such as Allen and o counties where they are buried, there may be note-y changes in many respects. Information from well valuable in proportion as the record is carefully made rrectly interpreted. From a good well record it should

GEOLOGICAL SECTIONS IN ALLEN AND NEOSHO COUNTIES.

	T. 30 S. R. 17 E.	T. 29 S. R. 19 E.	T. 29 S. R. 18 E.	T. 29 S. R. 17 E.	T. 27-28 S. R. 19 E.	T. 27-28 S. R. 18 E.	T. 26 S. R. 20 E.	T. 26 S. R. 19 E.	T. 26 S. R. 18 E.	T. 25 S. R. 18 E.	T. 23-24 S. R. 19 E.
Lansing formation:	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Stanton limestone											30
Vilas shale											30
Plattsburg limestone				20-50						7	
Lane shale				94-127				38	38	51	125
Kansas City formation:											
Iola limestone	10		1-6	2-20		40	30	30	30-45		40
Chanute shale	44-64	60	52	40-60		34			25-30		
Drum limestone	50?	1-3	1-3	6-8		35?	95*	95*	4-12		
Cherryvale shale	60	43-78	31								
Winterset limestone	25	30-50			48-55		30-42				
Galesburg shale		10-65			15-20						
Bethany Falls limestone		8-10									

* Drum limestone not found.

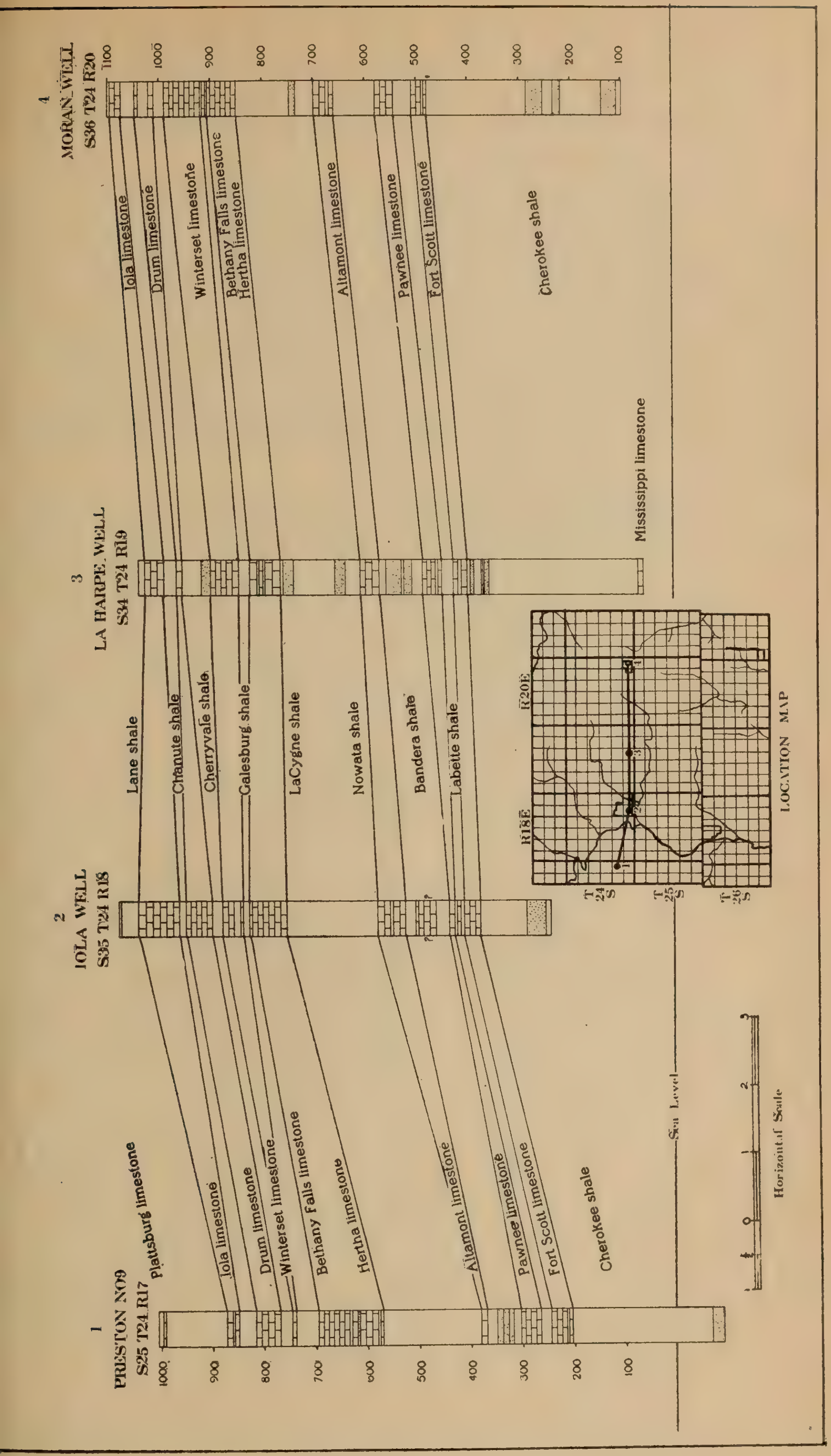

1
PRESTON NO9
S25 T24 R17
2
IOLA WELL
S35 T24 R18
3
LA HARPE WELL
S34 T24 R19
4
MORAN WELL
S36 T24 R20
Plattsburg limestone
Iola limestone
Drum limestone
Winterset limestone
Bethany Falls limestone
Hertha limestone
Altamont limestone
Pawnee limestone
Fort Scott limestone
Cherokee shale
Lane shale
Chanute shale
Cherryvale shale
Galesburg shale
LaCygne shale
Nowata shale
Bandera shale
Labette shale
Mississippi limestone
Sea Level
Horizontal Scale
0
1
2
3
LOCATION MAP
R18E
R20E
T 24 S
T 25 S
T 26 S
1100
1000
900
800
700
600
500
400
300
200
100

PLATE II.

be possible to identify the buried geological formations a determine their essential characters. It is very desirable almost all cases for the purposes of geologic study of subs face conditions to secure samples of the drill cuttings at tervals of every few feet.

Records of typical wells in the Allen and Neosho cou fields show that there are a number of good producing oil a gas sands, the most important of which are in the Cherol shale. A study of the logs indicates that most of the sands lenticular in shape, in some cases thick sands pinching out surprisingly short distances, or that they grade laterally i shale. The nonpersistent character of some of the sands this region is shown in figure 2, which shows partial logs wells just east of Chanute.

The following table shows the depth of the producing sar in a number of typical wells and their initial production:

RECORD OF PRODUCING SANDS IN ALLEN AND NEOSHO COUNTIES.

Location.			Depth to producing sand, feet.	Thickness penetrated, feet.	Initial production.
Section.	Twp.	Range.			
35	24	18	855	85	Gas.
35	24	18	792	35	Oil.
9	25	18	630	....	....
11	25	18	617	14	Oil.
4	26	18	775	18	Oil.
4	26	18	795	7	Oil.
4	26	18	864	14	Oil.
20	26	18	816	27	Oil.
22	26	18	755	8	Oil.
22	26	18	790	43	Oil.
22	26	18	776	7	Oil.
22	26	18	798	28	Oil.
22	26	18	767	10	Oil.
22	26	18	804	28	Oil.
26	26	18	764	8	Oil.
26	26	18	834	14	Oil.
26	26	18	798	25	Oil.
26	26	18	823	13	Oil.
26	26	18	808	13	Oil.
26	26	18	835	....	....
27	26	18	833	5	....
27	26	18	844	12	....
27	26	18	872	12	Gas 1000 M. cu.
16	26	20	685	....	....
34	26	20	780	....	Oil, 35 bbls.
25	27	17	890	20	Oil, 12 bbls.
36	27	17	893	17	....
14	27	18	748	17	....
29	27	19	698	12	....
			747	28	....
6	28	19	735	....	Oil, 150 bbls.
20	28	20	550	35	....
	28	19	750	28	Oil, 35 bbls.

SECTION ACROSS NEOSHO COUNTY

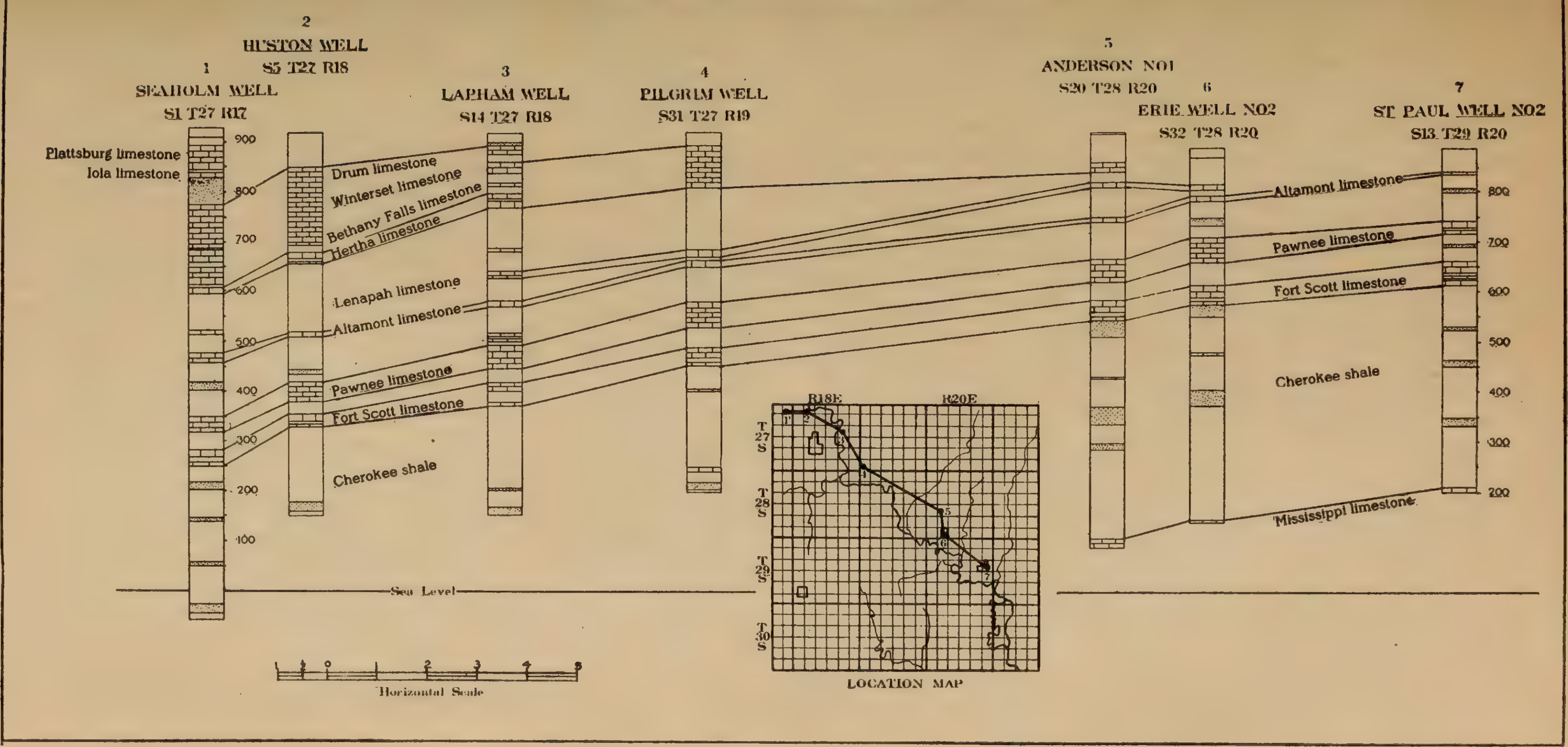


PLATE III.

Among the most interesting of the well records from th part of the state is that of a deep well drilled in S. 24, T. 2 R. 18, at Iola. It reached a total depth of 3,434 feet, but a cording to samples which were secured, and which are no filed in the office of the Geological Survey, the well did n reach granite. Since a well recently drilled near Yates Cente Woodson county, not more than twenty miles distant, encou tered granite at a depth of 2,585 feet, there is apparently slope of the granite surface toward the east in this area whic amounts to nearly 1,000 feet in 20 miles. So far as know the greater thickness of sedimentary rocks beneath the surfac in the vicinity of Iola, and probably the adjacent parts of All and northwest Neosho county, does not have a significant bea ing on the accumulation of oil and gas in the area. It is i teresting, however, to observe that the oil and gas fields of th two counties lie above the east-sloping granite (and eas dipping lower sedimentary rocks), while on the west side o the granite, at Yates Center, there has been very little pr duction until the Butler county fields far to the west, whic are also associated with an uplifted portion of the granit are reached.

OIL AND GAS PRODUCTION.

The chief producing fields in Allen and Neosho counties ar in the vicinity of Iola, Humboldt, Chanute and Erie. The dis tribution of oil and gas wells, dry and abandoned holes, so fa as the data are available, is shown on the accompanying ma plate IV.

Production of natural gas has, in the past, been most im portant in the Iola and parts of the Chanute field. At presen there is larger production of gas near the towns of La Harp and Gas in Allen county. The amount of gas obtained fro wells in this region has steadily diminished in recent year despite the drilling in of good new gas wells in parts of th field. Near Iola very many wells have been abandoned. It ap pears that in part of this area at least good new supplies o gas may be obtained by drilling between old locations, or i some cases by drilling to deeper sands. Most of the availabl supply of natural gas in these fields has, however, been ex hausted and both domestic and industrial consumers are fin ing it necessary to draw upon supplies from other sources.

e oil produced in Allen and Neosho counties comes chiefly the fields about Chanute, Humboldt, Moran, and Erie. wells are rather small producers, on the average, and a relatively heavy oil, much of it below 25 degrees Baumé ity. The average initial daily production is about 25 els, but some wells have an initial production of 250 els or more. After a few months the production settles o 20 barrels per day. In most parts of the area the wells an unusually long life, in some cases producing for as as twenty or more years. The producing sands are found allow depths, 600 to 1,000 feet below the surface. The ge depth of the important sands is about 600 and 800 respectively. Many of the wells have not been drilled gh the Cherokee shale and it is possible in some to test er sands. So far as reported, only one well, that at Iola, been drilled deep into or through the Mississippian. ther production of oil from breaks in the limestone of this m in Allen and Neosho counties is possible is yet un- n. The discovery of large quantities of oil in the Missis- an south and west of this area makes desirable the testing nditions in favorable structure in southeastern Kansas. though from 500 to 700 new oil wells have been brought ch year in these counties for the past four or five years, otal production has not been as large as might be expected. is partly due to the average small production per well and y to the low gravity of the oil. Recently, on account of the asing demand for petroleum products and the diminish- reserve in other fields, the price of the heavy crude has nced. The Standard Oil Company has offered $1.87 per el for oil between 10 and 26 gravity Baumé and has pro- l for advances in the price of low grade oil amounting to er cent of the advances in the price of high grade oil. This make possible the profitable operation of many wells which been idle and will bring to the oil fields of the entire dis- renewed activity. As the demand for crude oil becomes er, much of the possible oil-producing territory in these adjacent counties will be prospected and known fields will ore intensively developed. The importance of the shallow s of Allen and Neosho counties is, therefore, by no means rely a matter of history.

The Iola field. The Iola field comprises the area about the town of Iola, including especially the country north and east as far as Gas and La Harpe. Production has chiefly consisted of natural gas. The Iola field has been, indeed, one of the most important gas fields in Kansas and still supplies most of the local demand, which includes large industrial consumers. Some of the gas wells have produced more than 25,000,000 cubic feet per day. An important gas-producing area at the present time covers about ten square miles between Iola and Carlile and another lies between Iola and La Harpe. The relatively rapid decline of the gas fields near Iola is chiefly due to the unnecessarily large consumption of domestic consumers in the early years of the field when it was assumed that the supply of gas was inexhaustible, and to the large demands of industrial users. It is important that the remaining supply be developed as conservatively as possible. It is now generally realized that natural gas, the most valuable of all the natural fuels, is a very readily exhaustible substance and that when used or lost the supply is permanently decreased. In view of this fact it may be anticipated that the price of natural gas in the Iola and other gas fields of the state will increase until the cost equals that of artifically produced gas. Since natural gas has many times greater heat efficiency than artificial gas there is need both for the greatest practicable economy of consumption of the natural gas resources of the state and for the most efficient possible development of old and new gas fields.

A small amount of oil is produced in the Iola field, the oil wells being located chiefly in the valley of Neosho river west of Iola and along Deer creek, some four miles north of the town. The production of these wells is not large, probably not averaging more than 10 barrels per day.

The Moran field. In the vicinity of Moran, in eastern Allen county, there are two productive areas which may be considered under the name of the Moran field. One of the areas extends from the west edge of Moran westward and slightly south to within three miles of La Harpe. The other, which has been developed more recently, lies about four miles east of Moran and trends in a direction slightly north of east to south of west. The development of this oil field began about 1903 and production has been maintained to the present time. Since the formations are not so deeply buried in this part of the

as farther west, the oil is obtained at shallower depths
at Iola and Chanute. The amount of oil obtained from
individual well is small and the oil is heavy, like that at
boldt and Chanute.

e Humboldt field. A productive area which for con-
ence may be designated as the Humboldt field, covers a
iderable portion of southwestern Allen county in the vi-
y of the town of Humboldt. To the north, production has
extended until it practically joins the southeast extension
e Iola field. Southward the productive area expands
rd the county line and unites with the Chanute field. Al-
gh the portions north and south of the county line are, as
resent developed, parts of a single productive area in
h essentially the same geological and development condi-
obtain, the Allen county area may be included in the
boldt field and the Neosho county area in the Chanute
. The most active early drilling in the Humboldt field was
903, operations extending southward from Humboldt.
ling was at first centered chiefly in the Neosho river valley,
wells have later been drilled both east and west of the
until at the present time the field is more than nine miles
. The wells in the Humboldt field are rather small but
y long-lived producers. The oil is heavy, ranging from
t 12 to 30 Baumé. Very little gas is produced in the
. The average depth of the producing sands in the
rokee shale is from 800 to 900 feet.

he Chanute field. A large area in northwestern Neosho
ty, which has for many years produced oil and gas, may
esignated as the Chanute field. Northward it extends to
county line and adjoins the Humboldt field in Allen county.
extension northeastward projects a distance of ten or
ve miles from Chanute, and to the south and east produc-
extends almost to the Erie field. The Chanute field be-
e an important oil-producing area about 1901. Drilling
at first largely confined to the valley of Neosho river east
northeast of Chanute, but in 1903 drilling was rapidly
nded in all directions from the town. Production was
d northward as far as the Humboldt field and a good deal
gas and some oil were obtained as far south as Earlton.
duction in the Chanute field is found in sands about 600 to
feet below the surface, the thickness of the sands ranging

from 1 to more than 35 feet. In many instances, but not in all, the oil sands overlie those containing gas.* A bed of shale about 40 feet thick separates the two main producing sands One of the striking features in the Chanute field is the irregularity of the sands. In some instances a sand 30 to 40 feet thick is known to disappear within a distance of less than 500 feet. Figure 2 illustrates the sand conditions reported in wells just east of the town of Chanute. Gas wells developed in the Chanute field have had an initial capacity of 1,000,000 to 4,000,000 cubic feet daily, and in some cases much larger production. The oil obtained in the Chanute field is a heavy oil and the wells are rather small but good producers. Although this is one of the oldest fields of the state its importance as an oil producer is apparently by no means ended.

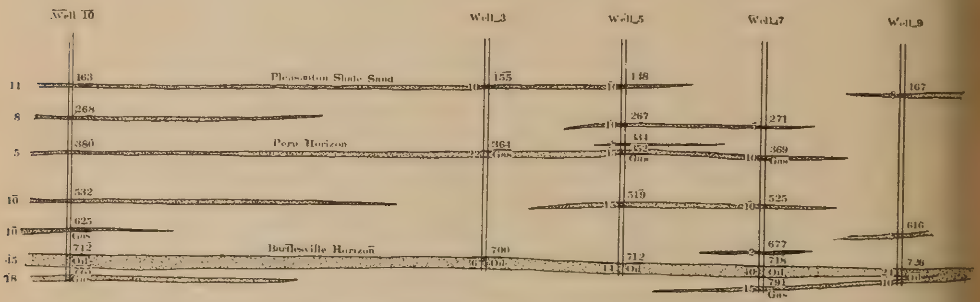


FIGURE 2.—Diagram showing irregular sand conditions in wells east of Chanute. Horizontal and vertical scale same.

The Erie field. Prospecting for oil and gas in the vicinity of Erie began about 1900. The main portion of the Erie field lies north and west of the town, the productive area covering approximately 18 square miles. Although some of the wells are very good, the production has not been as large as in the Chanute field. Most of the wells produce a heavy oil which is obtained from sands in the Cherokee shale. The surface formation in most of the field is the Hertha limestone and the superjacent shale. The depth to the sands ranges from 600 to 800 feet.

Other fields. A number of small productive areas have been developed in Allen and Neosho counties. Some of them may be considerably extended and it is possible that new areas of production may be found.

---

* Haworth, Erasmus, Special Report on Oil and Gas: Kan. Univ. Geol. Survey, vol. 9, p. 168, 1908.

ew fairly good oil wells have been developed in the vicin- Thayer, about ten miles south of Chanute, which pro- a heavy oil at comparatively shallow depths. There is ome oil and gas production between Thayer and Gales- and there are some gas wells near Galesburg. A few ells are found in the southeast part of Neosho county St. Paul southward along Neosho river, but none of these rge producers.

ently a very good field yielding a good quality of oil has leveloped southwest of Bronson, extending from Bour- ito eastern Allen county. The field is favorably located reference to local structure and promises a very satis- y production.

neries. On account of convenient access to the oil fields s and adjoining oil-producing areas, a number of re- es have been built in Allen and Neosho counties. The ing list shows the refineries which were in operation in 1920:

Refineries in Allen and Neosho counties.

Name and Location.	Daily capacity, barrels.
mmonwealth Oil and Refining Co., Moran	800
ller Petroleum Co., Humboldt	1,000
ıtual Oil Co., Chanute	1,000
ıclair Refining Co., Chanute	2,000
nnetonka Refining Co. (under construction), Humboldt,	....

following table shows the number of new wells com- in Allen and Neosho counties from 1904 to 1919, in- e:

AR.	Allen county.				Neosho county.			
	Oil.	Gas.	Dry.	Total.	Oil.	Gas.	Dry.	Total.
	387	....	63	450	454	....	65	519
	7	3	3	13	97	27	31	155
	....	2	....	2	68	61	36	165
	6	37	2	45	7	87	18	112
	22	133	37	192	30	54	34	118
	16	100	35	151	18	65	17	100
	13	51	14	78	9	61	17	87
	30	19	10	59	16	21	22	59
	50	2	6	58	62	30	23	115
	154	6	11	171	257	32	27	316
	175	8	10	193	221	23	19	263
	49	13	3	65	92	43	9	144
	314	6	6	326	237	6	8	251
	230	1	5	236	297	11	20	328
	254	6	37	297	443	17	75	535
	217	2	14	233	250	3	59	312

The following tables show the total and average initial production of new wells in Allen and Neosho counties from 1911 to 1919, inclusive, by years, and the total initial production by months from 1916 to 1919, inclusive:

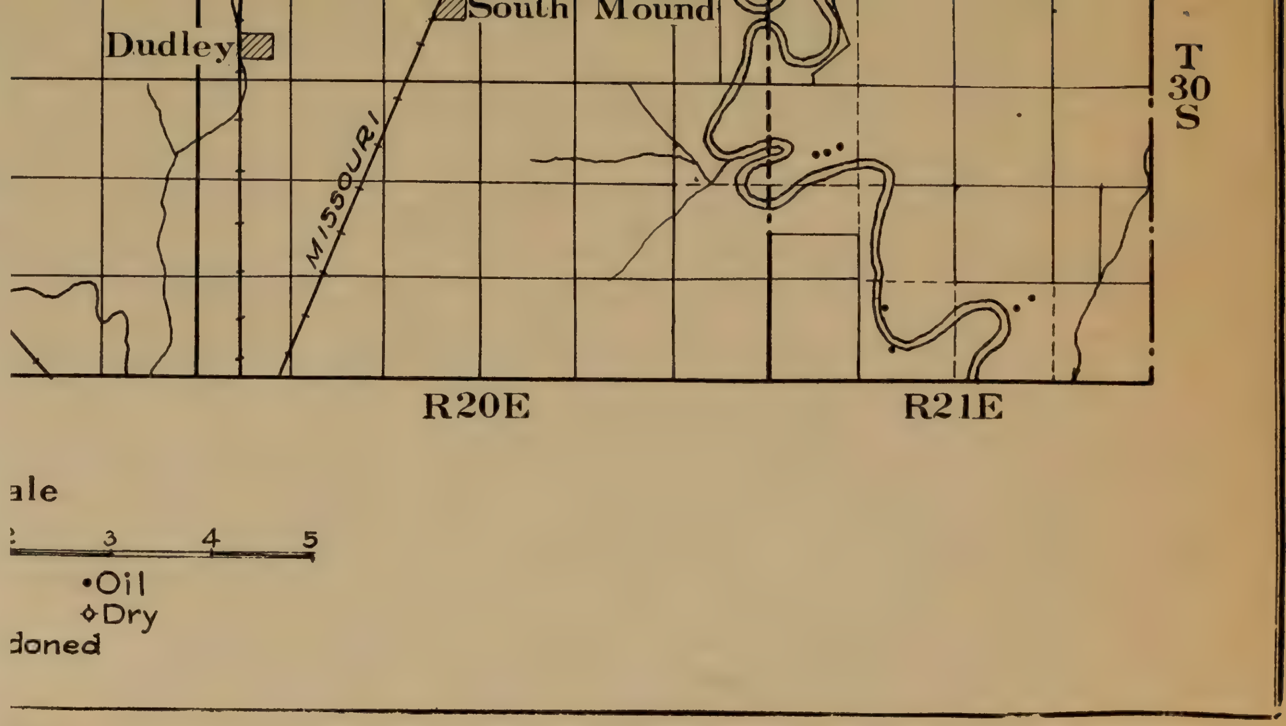
TOTAL AND AVERAGE INITIAL DAILY PRODUCTION OF NEW WELLS IN ALLEN AND NEOSHO COUNTIES, 1911 TO 1919, INCLUSIVE, IN BARRELS.

YEAR.	Allen county.		Neosho county.	
	Total initial production, in barrels.	Average per well, in barrels.	Total initial production, in barrels.	Average per well, in barrels.
1911	353	11.8	208	13.0
1912	1,632	12.6	693	11.2
1913	2,960	19.2	5,168	20.1
1914	1,896	10.8	2,414	10.9
1915	500	10.2	1,182	12.5
1916	3,773	12.0	3,354	14.3
1917	2,630	11.4	5,187	17.4
1918	2,812	11.0	6,509	14.9
1919	5,410	24.9	6,660	26.6

INITIAL DAILY PRODUCTION IN BARRELS OF NEW WELLS DRILLED IN ALLEN AND NEOSHO COUNTIES FROM 1916 TO 1919, INCLUSIVE, BY MONTHS.

MONTH.	Allen county.				Neosho county.			
	1916.	1917.	1918.	1919.	1916.	1917.	1918.	1919.
January	130	280	50	366	125	185	300	319
February	150	285	93	92	215	455	55	450
March	435	140	326	228	305	165	562	252
April	540	70	169	563	550	250	641	636
May	582	133	305	867	429	275	696	822
June	475	205	348	734	465	785	927	1,040
July	807	200	284	518	605	995	987	637
August	151	635	224	767	125	440	707	969
September	73	48	310	385	100	365	433	675
October	85	215	296	440	95	305	594	520
November	220	187	173	175	160	438	310	134
December	165	232	324	275	180	529	297	207

□


South Mound
Dudley
MISSOURI
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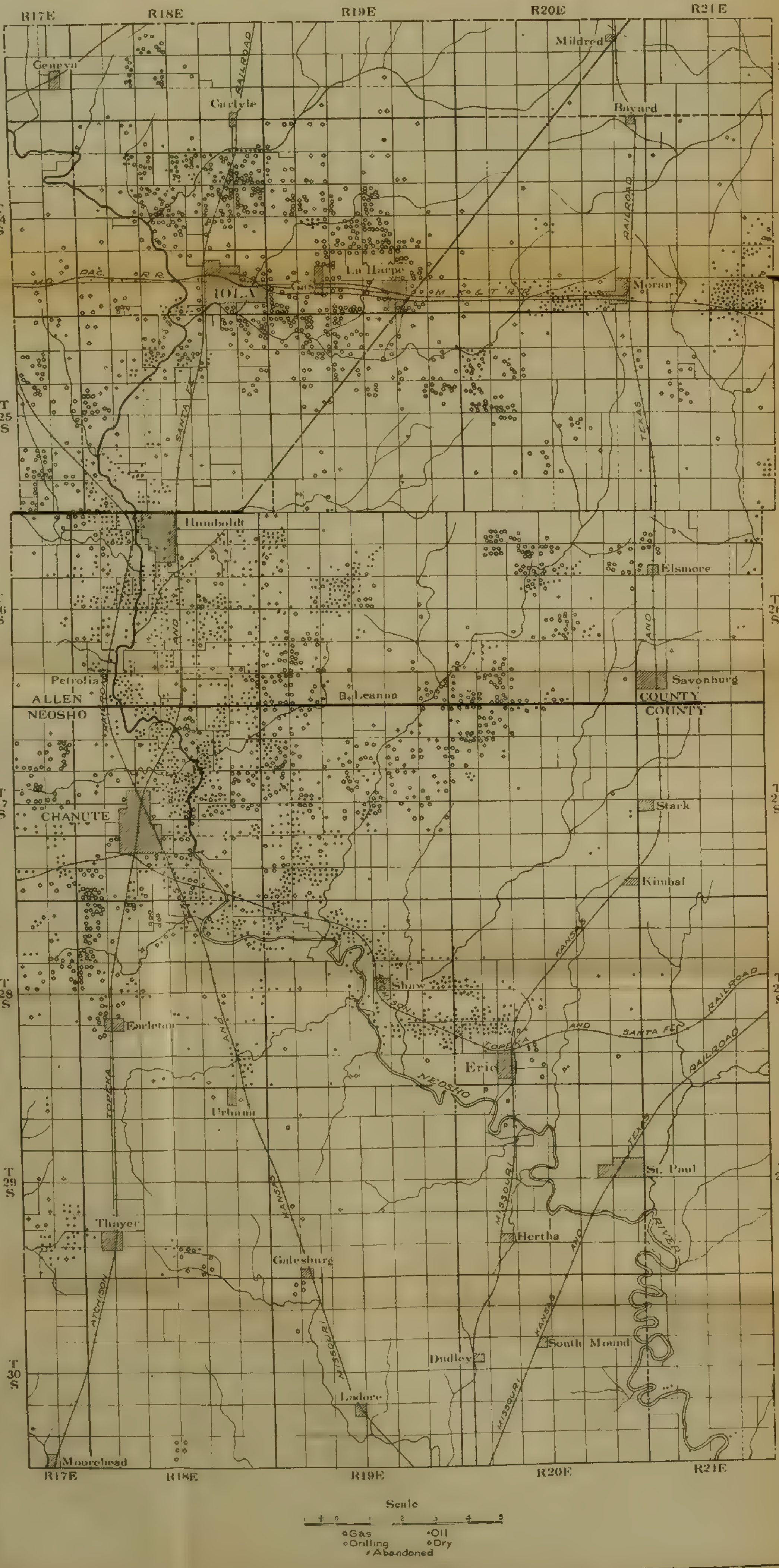
171

STATE GEOLOGICAL
SURVEY OF KANSAS

RAYMOND C MOORE
STATE GEOLOGIST

PRODUCTION MAP
OF
ALLEN AND NEOSHO COUNTIES, KANSAS



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STATE GEOLOGICAL SURVEY OF KANSAS
RAYMOND C. MOORE, State Geologist

OIL *and* GAS RESOURCES *of* KANSAS

PART VI

WILSON AND MONTGOMERY COUNTIES

By RAYMOND C. MOORE
AND
CHARLES W. BOUGHTON

BULLETIN 6

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TOPEKA, KANSAS

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CONTENTS.

PAGE
uction 5
ocation 5
opography and drainage 5
ılture 6
knowledgments 7
y of development 7
y 8
ırface formations 8
ructure 13
    Relation of structure to production 13
ıbsurface geology 15
    Sandstone horizons 15
    Deep wells 16
    Possibilities of Mississippian production 16
l gas production 17
ilson county 17
    Introduction 17
    The Neodesha field 19
    The Altoona-Vilas field 20
    The Fredonia field 21
    The Benedict-Buffalo field 22
    Records of development in Wilson county 23
ontgomery county 24
    Introduction 24
    The Bottom Field 25
    The Wayside-Havana field 25
    The Independence field 27
    The Tyro field 28
    The Coffeyville field 29
    The Cherryvale field 29
    The Elk City field 30
    The Larimer-Sycamore field 30
    Records of development in Montgomery county 31
efineries 32

ILLUSTRATIONS.

PLATE I. Geological map of Wilson and Montgomery counties.....
II. Structure map of Independence Quadrangle.............
III. Production map of Wilson and Montgomery counties....
IV. Geological cross section of correlated well records from Cherryvale, Montgomery county, west into Cowley county.
FIGURE 1. Location map of Wilson and Montgomery counties.......
2. Decline curves of Neodesha oil field.....................
3. Decline in rock pressure in southeast Kansas gas fields...

Glen M Ruby

OIL AND GAS RESOURCES OF WILSON AND MONTGOMERY COUNTIES, KANSAS.

By RAYMOND C. MOORE and CHARLES W. BOUGHTON.

INTRODUCTION.

Location. Wilson and Montgomery counties are situated southeastern Kansas, approximately fifty miles from the ssouri state line to the east, and bordering the Oklahoma te boundary on the south. Together they form a rectangle enty-four miles in width from east to west and fifty-one es in length from north to south, an area of approximately 00 square miles. (See location map, figure 1.) The areal

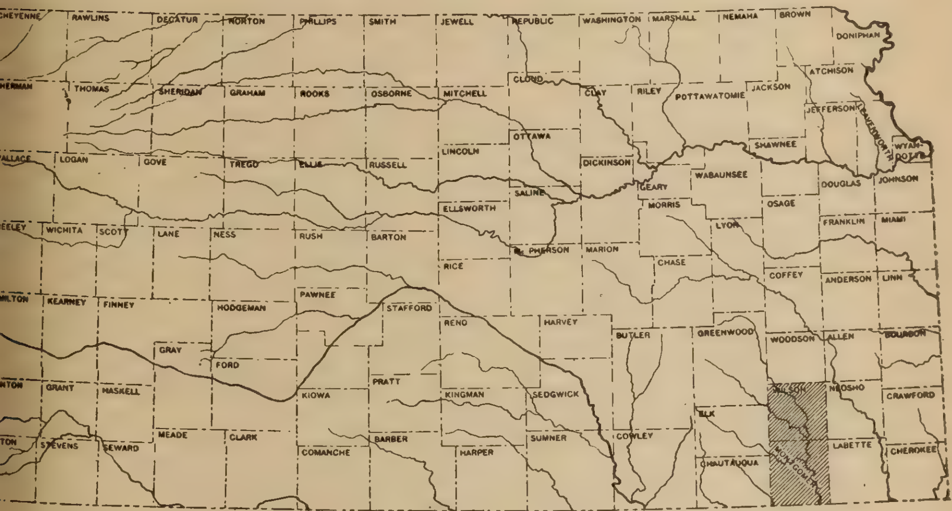

FIGURE 1.—Location map of Wilson and Montgomery counties.

l structural geology of these two counties is much the same, l for this reason they may conveniently be considered as a it in this report.

Topography and drainage. Wilson and Montgomery couns are a typical portion of the plains country of eastern nsas and Oklahoma. The chief topographic features are arpments formed by resistant beds of limestone and sandne, the positions of which are for the most part shown on e geological map (plate I). These escarpments are most ominent where massive hard beds overlie a considerable ickness of shale, as in the base of the Stanton-Plattsburg escarpment. In some cases they are more than 200 feet hi The steep slopes are, broadly speaking, to the east, while w of the escarpments are more or less extended, nearly le areas which reach to the base of succeeding escarpments. T nearly level country, five to eight miles in width, west of V digris river, about Independence and to the south, lies betw the escarpments of the Drum and Stanton limestones. Loca as between Elk City and Bolton, where erosion has cut ba deeply and irregularly into an escarpment, the topography very rough. In a number of places outliers of limestone a sandstone form prominent knobs or hills, commonly known this region as mounds. Examples are Walker mound a Table mound near Independence and Twin mounds south Fredonia. The sandstone hills, which are in the southw part of the area, north of Caney and Havana, are covered b dense growth of scrub oak. Geological work in the sandsto country is much more difficult than in other parts of t region.

The elevation of the region ranges from high points in we ern Wilson county, which exceed 1,100 feet above sea level, 690 feet in the Verdigris river valley south of Coffeyvi which is the lowest elevation in Kansas. The average ele tion of the two counties is about 875 feet.

The drainage in Wilson and Montgomery counties is towa the south and southeast. The largest stream, Verdigris riv enters Wilson county near the northwestern corner and flo in an irregular course southward to the southeast corner Montgomery county. Neodesha, Independence and Coffeyvi are located in its valley. Other important streams are F river, which joins the Verdigris from the west at Neodes and Elk river, which flows eastward across north central Mo gomery county into the Verdigris near Independence. Sm tributary streams east of the Verdigris river flow southwe

Culture. The area included in Wilson and Montgome counties is a rich farming country. For this reason, a largely as the result of extensive oil and gas development, t population is large and there are within the area an unus number of prosperous towns and cities. The most importa cities are Independence, Cherryvale and Coffeyville, in Mo gomery county, and Fredonia, Neodesha and Altoona, in W son county. Numerous industrial activities center in t region.

tersecting lines of four railroad systems—the Atchison, ka & Santa Fe, the Missouri Pacific, the St. Louis & San cisco, and the Missouri, Kansas & Texas—provide a close ork of railway transportation which serves excellently arts of the area. An electric interurban connects Coffey- Independence and Cherryvale, and extends eastward to ons in Labette county. Good automobile and wagon roads readily accessible almost all parts of the region.

knowledgments. Since Wilson and Montgomery counwere among the first in Kansas to produce oil and gas rge quantities, they have received attention in a number eports of the United States Geological Survey and the sas Geological Survey. These reports have been freely in this publication, and reference is given wherever pos- . The Survey is indebted to the Empire Gas and Fuel pany for the use of their outcrop maps and vertical sec- in this area.

HISTORY OF DEVELOPMENT.

out 1860 a number of shallow wells which yielded oil and es of natural gas were drilled in southeastern Kansas. In small quantities of gas were found at a number of places Independence. A company formed there for the purpose ining coal drilled a well in 1884 and found gas at 1,200 The gas became ignited, did much damage, and was doned without any attempt to use it. In 1889 gas was d in moderate quantities near Cherryvale, and about a later at Coffeyville, the gas being piped to Independence Cherryvale in 1893.[1] At first the supply was small, but 1902 to 1904 a number of wells were drilled which had nitial open-flow capacity ranging from 12,000,000 to 37,000 cubic feet of gas daily.

ontgomery county became an oil-producing district in , with the opening of the Bolton pool, which in 1904 had 200 producing oil wells. A few of these wells had an al production of 1,000 barrels a day, and 150- to 200-barrel s were quite common. At present there is no sharp divi- between the various oil and gas fields of Montgomery county, and the early fields near Independence, Bolton, Wayside and Havana might now properly be classed as one large producing district.

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[1] Schrader, F. C., and Haworth, E., loc. cit. pp. 20-22.

Prospecting for oil and gas began in the vicinity of Neodesha in 1890, and the results were sufficiently attractive to interest the Pittsburg firm of Guffey & Galey. They secured a number of good oil wells near Neodesha, but prospected at many other points in eastern Kansas with but little success.[2] Recent developments show that many of the dry holes drilled by this firm were practically on the edge of productive oil pools. In 1895 Guffey & Galey sold their Kansas holdings to the Forest Oil Company, which was later reorganized, and is to-day known as the Prairie Oil and Gas Company. Gas was first lighted in Neodesha, July 4, 1894. The towns of Fredonia, Benedict and Buffalo became oil and gas centers about 1900.

GEOLOGY.

SURFACE FORMATIONS.

The rocks exposed at the surface in Wilson and Montgomery counties belong to the middle portion of the Pennsylvanian system. They consist of alternating beds of shale, limestone and sandstone, the shale amounting to approximately 70 per cent of the total thickness. The limestones, and locally the sandstones, form more or less prominent escarpments, those best defined occurring in the west portion of the area. The shales are commonly not well exposed on account of the readiness with which they weather. They form the nearly level or gently rolling topography between the escarpments. The dip of the strata in this region is to the west, so that in crossing either county from east to west one passes from older to younger formations.

The geologic divisions which outcrop in Wilson and Montgomery counties are the Marmaton, Kansas City, Lansing and Douglas formations. The relation of these divisions to other parts of the Pennsylvanian in Kansas, and the members of which they are composed, are shown in the following table. The divisions are arranged in the order in which they appear geologically, the lower formations below, and the upper above.

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[2] Haworth, E., Kansas University Geol. Sur., Special report on oil and gas, vol. 9, pp. 29-41, 1908.

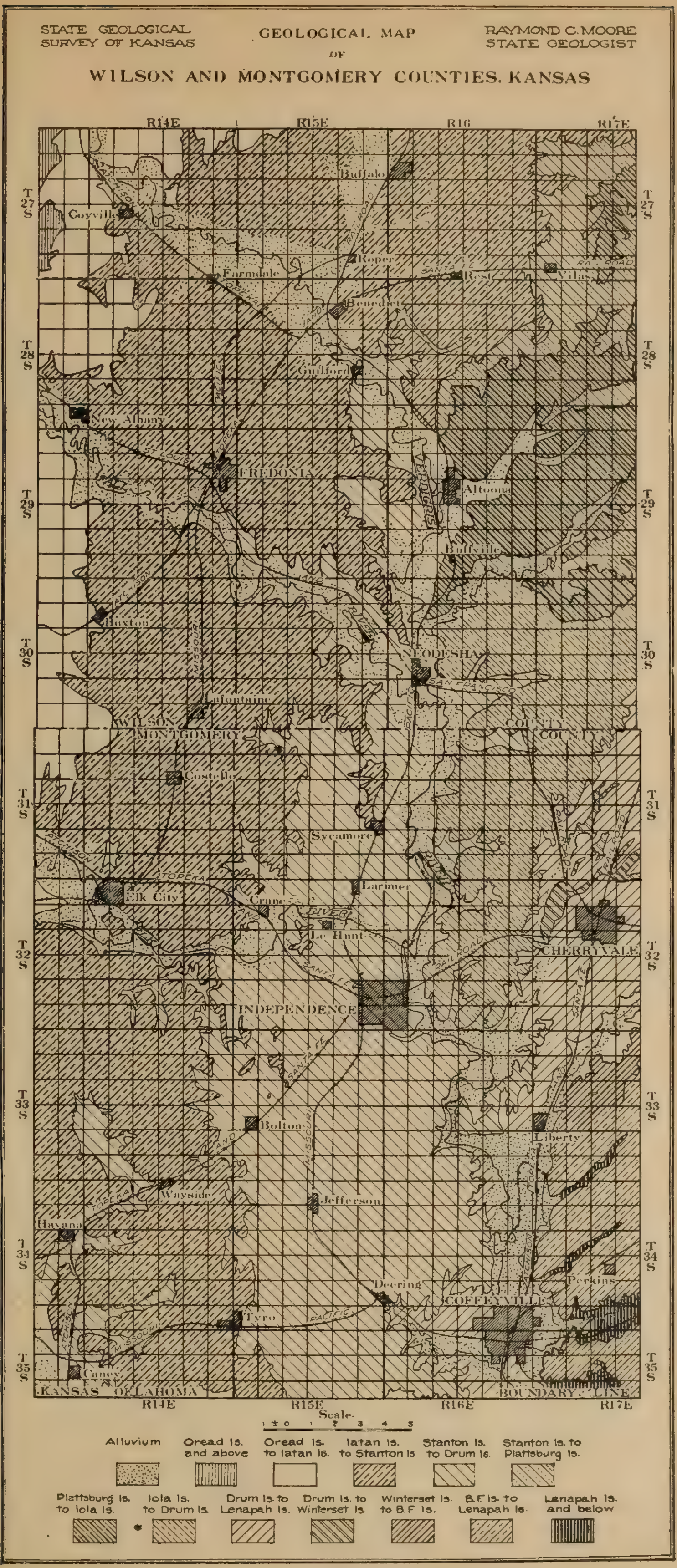
STATE GEOLOGICAL SURVEY OF KANSAS
GEOLOGICAL MAP OF WILSON AND MONTGOMERY COUNTIES, KANSAS
RAYMOND C. MOORE STATE GEOLOGIST
R14E
R15E
R16
R17E
T 27 S
T 28 S
T 29 S
T 30 S
T 31 S
T 32 S
T 33 S
T 34 S
T 35 S
Coyville
Buffalo
Roper
Rest
Vilas
Farmdale
Benedict
Guilford
New Albany
FREDONIA
Altoona
Buffville
Buxton
NEODESHA
Lafontaine
WILSON COUNTY
MONTGOMERY COUNTY
Costello
Sycamore
Elk City
Crane
Larimer
Le Hunt
CHERRYVALE
INDEPENDENCE
Bolton
Liberty
Wayside
Jefferson
Havana
Perkins
Deering
COFFEYVILLE
Tyro
Caney
KANSAS OKLAHOMA BOUNDARY LINE
SANTA FE
RAILROAD
MISSOURI
PACIFIC
TOPEKA
RIVER
SAN FRANCISCO
Scale
1 0 1 2 3 4 5
Alluvium
Oread ls. and above
Oread ls. to Iatan ls.
Iatan ls. to Stanton ls.
Stanton ls. to Drum ls.
Stanton ls. to Plattsburg ls.
Plattsburg ls. to Iola ls.
Iola ls. to Drum ls.
Drum ls. to Lenapah ls.
Drum ls. to Winterset ls.
Winterset ls. to B.F. ls.
B.F. ls. to Lenapah ls.
Lenapah ls. and below

PLATE I.

Table showing the geological divisions of Wilson and Montgomer counties, and their relation to other rock formations of Kansas.

- Quaternary.
  - Recent.
    - Alluvium (includes deposits along streams in Wilson and Montgomery counties).
  - Pleistocene.
    - Glacial deposits (northeastern Kansas).
- Tertiary (western Kansas).
- Cretaceous (western and north central Kansas).
- Comanchean (south central Kansas).
- Permian (central Kansas).
- Pennsylvanian (eastern Kansas).
  - Missouri group.
    - Wabaunsee formation.
    - Shawnee formation.
    - Douglas formation.
      - Oread limestone.
      - Lawrence shale.
      - Iatan limestone.
      - Weston shale.
    - Lansing formation.
      - Stanton limestones.
      - Vilas shale.
      - Plattsburg limestone.
      - Lane shale.
    - Kansas City formation.
      - Iola limestone.
      - Chanute shale.
      - Drum limestone.
      - Cherryvale shale.
      - Winterset limestone.
      - Galesburg shale.
      - Bethany Falls limestone.
      - Ladore shale.
      - Hertha limestone.
    - Marmaton formation.
      - La Cygne shale.
      - Lenapah limestone.
      - Nowata shale.

      (Douglas formation to Nowata shale:) Exposed in Wilson and Montgomery counties.

      - Altamont limestone.
      - Bandera shale.
      - Pawnee limestone.
      - Labette shale.
      - Fort Scott limestone.
    - Cherokee shale.
  - Mississippian (southeast Kansas).
  - Devonian and Silurian (?)
  - Ordovician
  - Cambrian
  - Pre-Cambrian

  (Devonian to Pre-Cambrian:) Not exposed in Kansas.

The Marmaton formation outcrops in the southeast corne of Montgomery county, the exposures being limited chiefly t the valleys of Pumpkin, Big Hill and other tributaries of th Verdigris east of Coffeyville. Only the uppermost portion o the formation appears in Montgomery county. The Kansa City formation, which lies next above the Marmaton, may b traced from north to south across the central and eastern por

ns of Montgomery county and southeastern Wilson county.
e large content of limestone in the Kansas City formation,
ich characterizes exposures farther north, is not so evident
re. Neither the Hertha limestone at its base nor the Iola
nestone at its top have been traced across Montgomery
inty. One of the important members of the formation, the
um limestone, which is named from Drum creek, in Mont-
mery county, has a thickness of eighty feet locally in this
ea, but is very irregular in thickness. Its outcrop is shown
plate I. The Lansing formation is prominent in west cen-
l Montgomery county and across the central portion of
ilson county. The Stanton limestone at its top makes one of
e most striking escarpments in the area. It extends north-
rd from Tyro across Elk river halfway between Independ-
ce and Elk City, thence in an irregular line northeastward
o Wilson county toward Neodesha. It extends up Fall river
Fredonia and on either side of Verdigris river between Al-
na and Benedict, and is mapped northeastward past Vilas
the corner of the county. Almost all of western Mont-
mery county and northwestern Wilson county are occupied
strata belonging to the Douglas formation. The thin Iatan
nestone member has been identified in western Wilson county
d the Oread limestone appears at the extreme northwest
rner of the county.

The following measurements reported by geologists of the
npire Fuel and Gas Company show the thickness of the geo-
gic divisions in various parts of Wilson and Montgomery
unties.

Stratigraphic sections in Wilson and Montgomery counties.

T. 27-28 S., R. 15 E.

	Feet.
nsing formation:	
Stanton limestone:	
Upper ledge	15– 20
Shale	15
Lower ledge	20– 25
Vilas shale	87
Plattsburg limestone	17
Lane shale	48

T. 28 S., R. 14 E.

	Feet.
uglas formation:	
Oread limestone:	
Lawrence shale	210
Iatan limestone:	
Upper ledge	3– 5
Shale	8
Lower ledge	5
Weston shale	....

T. 31 S., R. 15 E.

	Feet.
Lansing formation:	
Stanton limestone	45
Vilas shale	10– 15
Plattsburg limestone	80
Lane shale	105
Kansas City formation:	
Iola limestone	2– 4

T. 27 S., R. 16 E.

Weston shale	....
Lansing formation:	
Stanton limestone	37
Vilas shale	85
Plattsburg limestone	17
Lane shale	48

T. 29 S., R. 15 E.

Lansing formation:	*Feet.*
Stanton limestone	60– 70
Vilas shale	10– 25
Plattsburg limestone	20– 80
Lane shale	....

T. 31-32 S., R. 17 E.

Kansas City formation:	*Feet.*
Iola limestone	3–
Chanute shale	5
Drum limestone	.
Upper ledge	3–
Shale	2
Lower ledge	10– 1
Cherryvale shale	70– 9
Winterset limestone	6– 1

Southward from the Wilson-Montgomery county area int Oklahoma the geological formations undergo changes which have made difficult the identification of corresponding stratigraphic units, especially since the field work in Kansas and Oklahoma has been done almost entirely by different groups of geologists. In view of the continuity of the oil and gas fields across the state boundary it is very desirable to determine the equivalents in Oklahoma of the stratigraphic units identified in Kansas. The following table shows as closely as possible the correlation of the Kansas divisions with those employed by the Oklahoma Geological Survey in the area adjacent to Montgomery county.

Table showing tentative correlation of stratigraphic divisions in Wilson and Montgomery counties, Kansas, with those in northeastern Oklahoma.

KANSAS.		OKLAHOMA.	
Divisions.	*Thickness, feet.*	*Divisions.*	*Thickness, feet.*
Douglas formation:			
Oread limestone	20– 60	Oread limestone	0– 17
Lawrence shale	200–300	Shale	170
Iatan limestone	5– 15	Labadie limestone	15– 20
Weston shale	60–100	Shale	100–150
Lansing formation:			
Stanton limestone	20– 40		
Vilas shale	50–125	? Avant limestone	0– 20
Plattsburg limestone	6– 80		
Lane shale	50–150	Shale and sandstone	125–200
Kansas City formation:			
Iola limestone	2– 40	Dewey limestone	23
Chanute shale	25–100	Shale and sandstone	75
Drum limestone	0– 80	Hogshooter limestone	10
Cherryvale shale	25–125	Shale and sandstone	300–400
Winterset limestone	5– 40	? Lost City limestone	1– 40
Galesburg shale	5– 60	Shale	170
Bethany Falls limestone	0– 22	? Checkerboard limestone	2– 10
Ladore shale	0– 40		
Hertha limestone	10– 20		
Marmaton formation:		Shale and sandstone	200
La Cygne shale	100–150	Dawson coal	8
Lenapah limestone	2– 10	Lenapah limestone	20
Nowata shale	70	Nowata shale	70

STRUCTURE.

The normal dip of the strata in Wilson and Montgomery nties is slightly north of west at the rate of twenty to enty-five feet per mile, but in many places this has been in- rupted by more or less pronounced folds. The structure of Independence Quadrangle is shown on plate II by means twenty-foot contours which represent the elevation of the anton limestone above sea level. This map was constructed m the topographic and geologic maps prepared by Schrader d Haworth in Bulletin 296 of the United States Geological rvey. The Stanton limestone is found only in the western lf of the quadrangle, so it was necessary to use a number of rying intervals in determining the elevation of the Stanton estone in the eastern half of the county. The resulting map by no means accurate in detail, and is used in this report to w as nearly as possible from data available the generalized ucture of the area.

It may be noted (plate II) that there is a well-defined fold the vicinity of Cherryvale, and a somewhat smaller fold east Coffeyville. Directly west of Coffeyville the beds are al- st flat, and between the Coffeyville and Cherryvale anti- nes there is another small fold, southwest of Liberty. Be- een this fold and Independence there is a rather pronounced ncline pitching toward the southwest. In the vicinity of odesha the strata are almost flat, although interrupted here d there by a number of small domes.

Relation of structure to production. One of the most im- rtant considerations in the development of any oil territory the relation between the apparent surface structure and the oducing oil and gas horizons. In Wilson and Montgomery unties these reservoirs consist of lenticular bodies of sand- one interbedded with shale. These sandstones are irregular d local in character, varying greatly in their horizontal and rtical extent. They do not form continuous and definite rizons, but pinch out laterally or grade into shale. Under ch conditions surface structure and production could not expected to have that fixed relation found in regions under- in by definite and continuous oil and gas sands.

The Cherryvale oil and gas district is situated on a broad ticline. Elk City gas field lies near the crest of two small mes.[3] Production south of Elk City is closely associated

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[3] Boughton, Charles W., The Elk City gas field, Kansas Geol. Survey, Bull. 5, 1920.

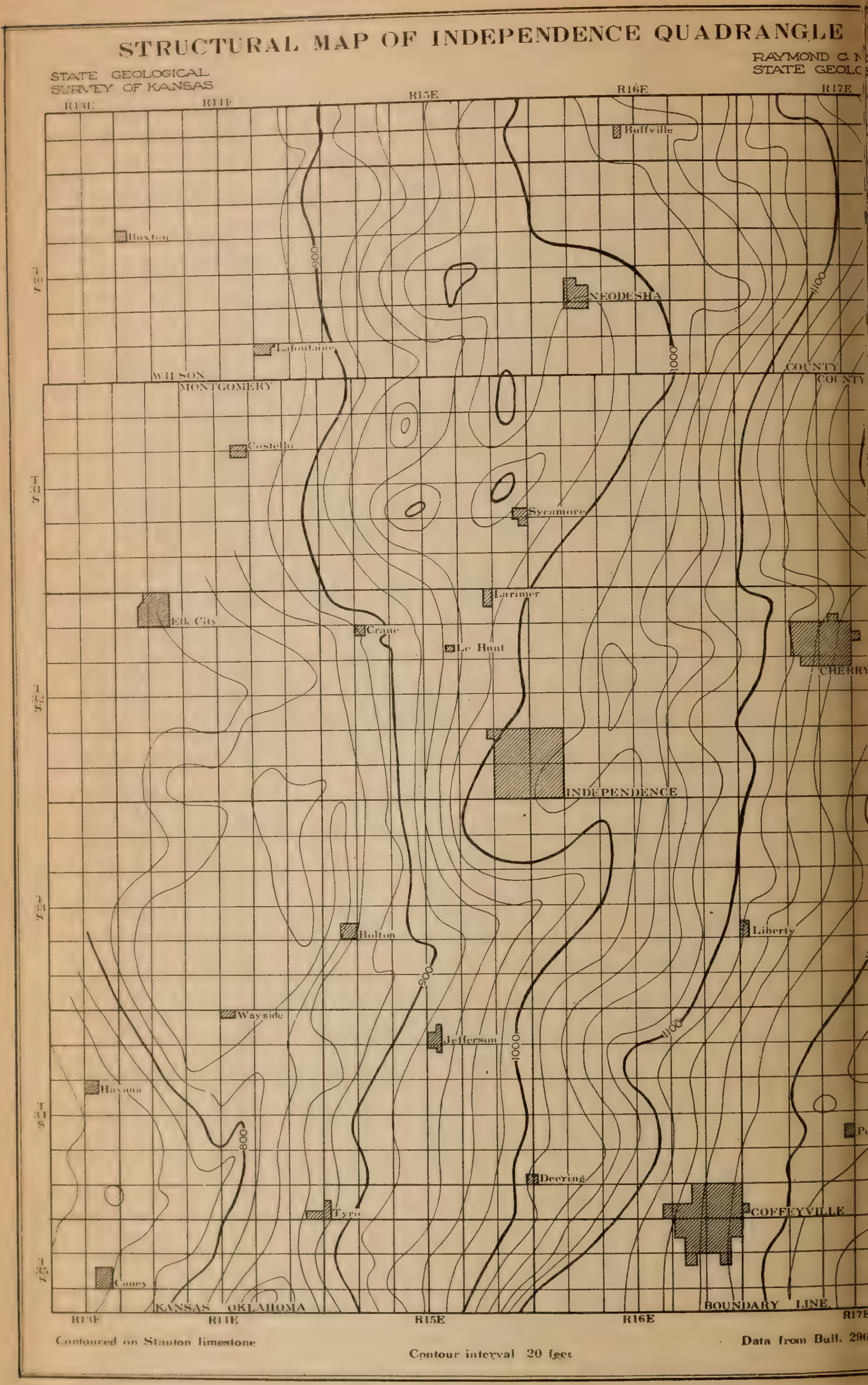
STRUCTURAL MAP OF INDEPENDENCE QUADRANGLE
STATE GEOLOGICAL SURVEY OF KANSAS
RAYMOND C. M
STATE GEOLO
R13E
R14E
R15E
R16E
R17E
T 30 S
T 31 S
T 32 S
T 33 S
T 34 S
T 35 S
Buffville
Buxton
NEODESHA
Lafontaine
WILSON
MONTGOMERY
COUNTY
COUNTY
Costello
Sycamore
Larimer
Elk City
Crane
Le Hunt
CHERRY
INDEPENDENCE
Bolton
Liberty
Wayside
Jefferson
Havana
Deering
Tyro
COFFEYVILLE
Caney
KANSAS
OKLAHOMA
BOUNDARY LINE
900
1000
1100
800
Contoured on Stanton limestone
Contour interval 20 feet
Data from Bull. 29

PLATE II.

a fairly large dome, and the oil found east and north of · occurs in small but pronounced terrace structures. s found south of Independence in a syncline, and oil oc- round Neodesha where the beds are almost flat. With- sufficient number of well records and their casing-head ions it is impossible to explain satisfactorily these irregu- s between surface structure and production. However, ears that a test well has the best chances for success located on a dome, anticline or terrace, and this is es- ly true of the western portion of this region, where the become somewhat more continuous.

SUBSURFACE GEOLOGY.

dstone horizons. The chief producing sands in Wilson ontgomery counties belong to the La Cygne, Bandera and kee shales. South of Fredonia gas occurs at a depth of 500 feet, in a sand which possibly belongs to the Cherry- hale. In the Wayside pool in Montgomery county the t-lived sand is the Wayside, which is a part of the La shale. About 150 feet below the Wayside sand is the r, which possibly corresponds to the Peru sand of Chau- a county. The third sand is the Bartlesville, found at a of 1,110 to 1,250 feet. Much of the gas in southwestern gomery county comes from the Burgess sand, which oc- just above the Mississippian limestone. At Coffeyville, the strata overlying the Cherokee shale are thinner than other point in this region, three sands are encountered oths of 350, 600 and 900 feet. The best wells, yielding 32° Baumé gravity, derive their oil from the 600-foot which possibly corresponds to the Weiser sand found in ayside and Bolton pools.

comparison the depth of the producing oil and gas sands icated in the following table:[4]

e showing depth of producing oil and gas sands in Wilson and Montgomery counties.

	Depth.	*Field.*	*Depth.*
	700 1,100	Fredonia	450 850 1,100
	1,100 1,400	Neodesha	800-900
ale	600-750	Sycamore	700-800 1,100-1,200
lle	350 600 900	Tyro	1,300
dence	450-600 1,100	Wayside	700 850 1,300

Schrader and Haworth, U. S. Geol. Survey, Economic geology of Independence ngle, Bull. 296, pp. 23-24, 1906.

The intimate association of dry holes with productive wells as in parts of the Wilson and Montgomery county fields, indicates that the country is "spotted" and that the oil does no occur in a single continuous sand body, but in disconnected lentils found at various horizons in the shale formations. The sandstones are merely reservoirs, and probably not sources of the oil and gas. The storage capacity of a reservoir of any given size depends on the texture of the rock, the shape and uniformity of the sand particles, and the amount of cementing material between these particles. The porosity of an ordinary fine-grained sand varies from 5 to 15 per cent. The sands that yield the most oil or gas are those which are completely sealed in by the impervious shale in which the sandstones are interbedded. The sands beneath the surface in southeastern Kansas are, as a rule, lenticular and rather variable in texture and degree of cementing. For this reason the hazards of drilling are larger than where sand conditions are very uniform.

Deep wells. Numerous wells in Wilson and Montgomery counties have been drilled into the Mississippian limestone but so far as known only two of these wells have penetrated to the bottom of this formation. The Neodesha deep wel passed through 263 feet of Mississippian at a depth of 1,100 to 1,364 feet, and was drilled on to 2,412 feet (see plate IV) Practically all of the Mississippian consisted of light-colored cherty limestone, without a trace of sand. The sandstones found at greater depths were so fine grained and tightly cemented that they could hardly serve as oil and gas reservoirs A well drilled near Caney in 1905 reached the Mississippian at about 1,600 feet, and was drilled on to 2,800 feet. Salt water and lack of funds prevented the well from going any deeper. It is reported that the bottom of this well was in a sandstone which showed considerable indication of oil. A pump was operated for a number of days in an attempt to exhaust the water, but succeeded in lowering the water only a few feet.[5] The Cherryvale deep well was drilled 216 feet into the limestone, from 1,004 to 1,220 feet, also without a reported trace of sand (see plate IV).

Possibilities of Mississippian production. The surface of the Mississippian limestone is quite irregular in this region and

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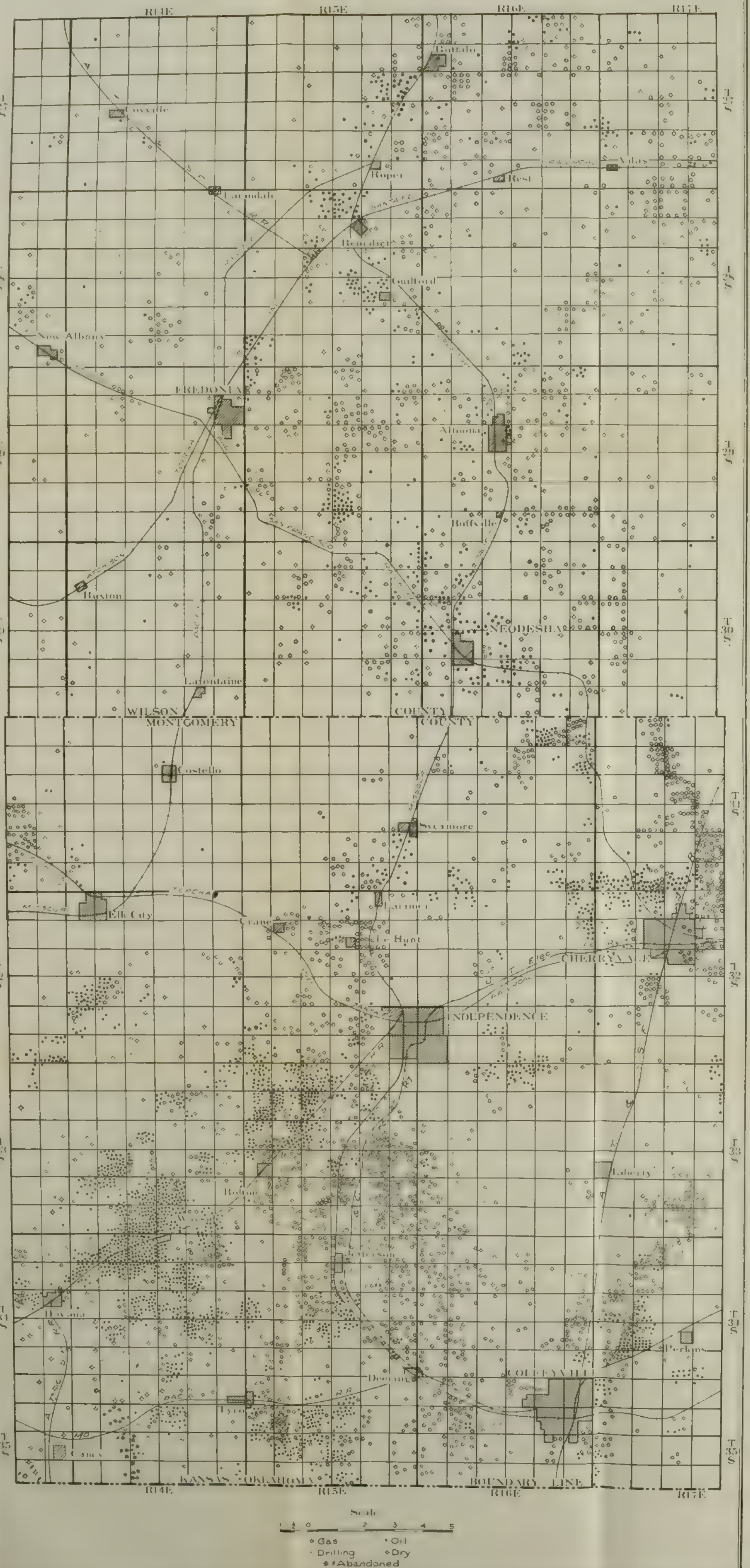
[5] Haworth, Erasmus, Kans. Univ. Geol. Survey, Special report on oil and gas, vol 9, p. 66.

PLATE III.

STATE GEOLOGICAL
SURVEY OF KANSAS

PRODUCTION MAP
OF
WILSON AND MONTGOMERY COUNTIES, KANSAS

RAYMOND C MOORE
STATE GEOLOGIST



4-1918

to the west at the rate of about thirty feet per mile. A ier of ridges and "domes" have been discovered by study ll records, all of which apparently represent pre-Pennsylvan erosion rather than folding. It is reported that the yvale anticline overlies a depression in the surface of lississippian, and that the syncline south of Independence ides with a Mississippian ridge.[6] On the other hand, a ul study of well records in the Elk City gas field has shown pparent surface structure overlies a very pronounced of Mississippian limestone.[7] To the west of this region lississippian has been found to contain one or more irar sandstones, containing salt water and traces of oil and ind it is reported that important production of oil has obtained from the Mississippian in Osage county and in county, to the south in Oklahoma.[8] It is very possible leep tests in favorable areas in Wilson and Montgomery ies, Kansas, where essentially similar geologic conditions il, may find important production in the Mississippian.

OIL AND GAS PRODUCTION.

WILSON COUNTY.

roduction. The chief producing districts in Wilson y are: (1) in the vicinity of Neodesha; (2) Altoona and rea northeast toward Neosho county; (3) the area suring Fredonia; and (4) the northern part of the county, g the territory about Roper, Benedict, and Buffalo. istribution of oil and gas wells, dry and abandoned holes, as the data are available, is shown on the accompanying plate III. Records are very incomplete in parts of the ind it is certain that many more wells have been drilled ire represented on the production map.

urvey of the distribution of oil and gas wells in Wilson fails to indicate the presence of sharply differentiated al-gas fields and oil fields. On the contrary, oil wells and lls appear to be closely associated in most of the fields in unty, and in many cases both oil and gas have been ob- from the same well. In a number of places gas is ob-

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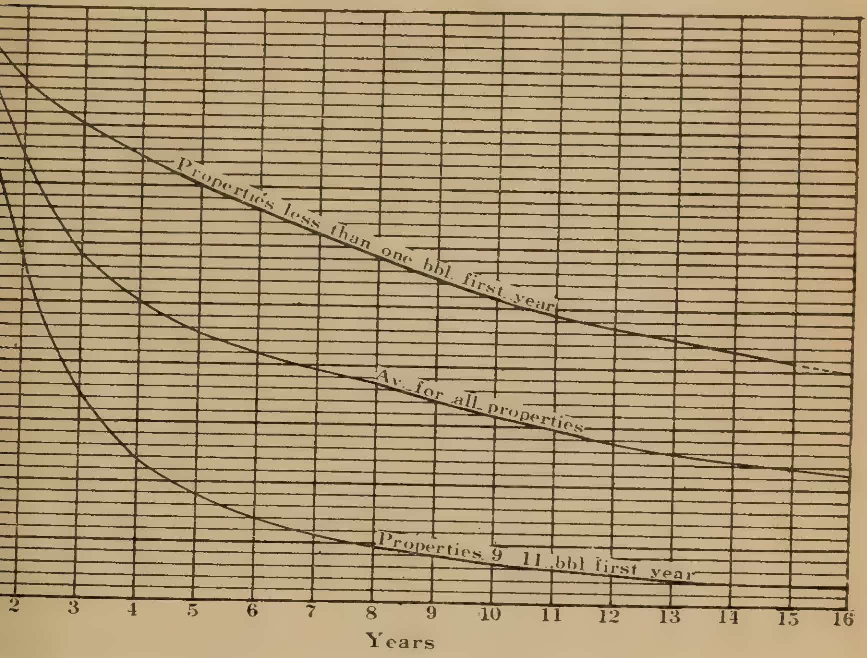
chrader, F. C., U. S. Geol. Survey, Independence Quadrangle, folio 159, p. 5.
oughton, Charles W., The Elk City Gas Field, Kan. Geol. Survey, Bull. 5, 1920.
urin, F., Pre-Pennsylvanian oil and gas horizons in Kay county, Oklahoma, Bull. n. Petrol. Geol., vol. 4, pt. 2, 1920.

tained from one sand and oil from another. The areas of mo
important gas production have been in the vicinity of Fredoni
about Neodesha and between Altoona and Vilas. Much of th
gas in the region has been exhausted, but it is evident that a
the resources of the county are by no means yet develope
The oil comes chiefly from fields near Neodesha between Bene
dict and Fredonia, and in the Benedict-Buffalo district. Th
wells are rather small producers, on the average, but yield
relatively high-grade paraffin base oil with a specific gravit
of 33° to 38° Baumé. The average initial production is fro
ten to fifteen barrels, but the amount of daily yield soon settl
to a very few barrels. As in most parts of southeastern Kan
sas, the wells have a long period of production, and in spite o
their small yield are quite profitable. The producing sand
are found at depths ranging from 350 feet in parts of th
county, to 1,000 feet. Many of the wells have not been drille
through the Cherokee shale, and it is possible in a number o
instances that deeper producing sands may be found. On
well drilled at Neodesha gives a record of the geological forma
tions beneath the surface to a depth of 2,412 feet. This, th
deepest well in Wilson and Montgomery counties, reached th
top of the Mississippian at a depth of 1,101 feet, its base a
1,364 feet, and drilled through sandstone, magnesian lime
stone, and dolomite of the Ordovician and Cambrian to 2,31
where it appears that granite was encountered. A diagram
matic log of this well appears on plate IV, well No. 13. A
though this well did not obtain oil or gas beneath the Cheroke
shale, it is not at all impossible that production may eventuall
be found under favorable structural conditions in "breaks" o
the Mississippian, or even beneath this series, in a manne
similar to recent discoveries in northern Oklahoma.

During the last few years from 100 to 300 new wells hav
been drilled in Wilson county each year. Although the propo
tion of dry wells has been only 9 to 12 per cent, the volume o
production has not been so large as might be anticipated. Th
is mainly due to the average small size of the wells. Howeve
the present high price of crude oil and the prospect of sti
higher prices, which results from the increasing demand fo
petroleum products and the diminishing reserve in other field
is bringing renewed activity to the fields of Wilson county an
adjacent parts of the southeast Kansas oil fields. In the futur

more intensive development and a wider prospecting anticipated in Wilson county.

Veodesha field. The Neodesha field comprises the oil- -producing area which is found on all sides of the town lesha, extending north approximately to Buffville, east th to the county boundaries, and west to the edge of production, some two or three miles from town. Oil re chiefly found in the central part of the field in the f the Verdigris. The oil from the Neodesha field is a ade paraffin oil, with specific gravity ranging from 33°



osite decline curves for wells of different output in the Neodesha oil field

FIGURE 2.

(From Carl Beal, U. S. Bureau of Mines, Bull. 177.)

aumé. There are numerous gas wells, especially north- Veodesha, in the outlying part of the area included for nce in the field.

opment in the Neodesha area began about 1890, a num- ood oil and gas wells being obtained immediately sub- to this date. In 1903 and 1904 some wells were in which showed an initial daily production of more) barrels. Production has in many cases been main- or a period of ten to fifteen years, and it is possible resent conditions that a number of abandoned wells itory could profitably be reopened.

The chief producing horizon is a sandy bed of the Cherok shale which is encountered in the vicinity of Neodesha at depth of 800 to 900 feet beneath the surface. The geologic formations which outcrop in southeastern Wilson county a older than those of other parts of the county, and it is co sequently a shorter distance to any given horizon beneath th surface than in the other fields of the county.

The rate of decline in the production of oil wells in the Ne desha district has been studied by Carl H. Beal[9] in work unde taken for the United States Bureau of Mines. Decline curv for the field, prepared by him, are shown in figure 2. In the curves the total production for the first year is taken as 100 p cent and the amount produced in each succeeding year is ca culated in percentage on the basis of the first year's outpu The upper curve (figure 2) shows the average decline of fi properties in the Neodesha field in which the wells average less than one barrel daily the first year. The lower curve re resents the composite decline of wells on three properties whe the wells during the first year produced from nine to eleve barrels daily. The middle curve gives the average decline of a wells on properties for which production records were availabl The first curve is of considerable interest, as it shows that well with an average daily output of less than one barrel wi average during the second year about 86 per cent of its fir year's production. For wells that average nine to eleve barrels daily the first year, the second year's production wi amount to about 57 per cent of that of the first. The averag initial production of the wells on fourteen properties fro which the average curve was compiled amounted to 3.9 barre daily during the first year.

One of the largest refineries in Kansas, that of the Standar Oil Company, is located at Neodesha. The first constructio was undertaken in 1897, when a small refinery with a capacit of 500 barrels a day was erected. Additions have been mad from time to time until at the present time the plant has capacity of 12,000 barrels a day. Much of the oil of south western Kansas is now transported to this refinery.

The Altoona-Vilas field. In eastern and northeastern Wilso county, occupying the area about and between the towns

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[9] Beal, Carl H., Decline and ultimate production of oil wells, with notes on t valuation of oil properties, Bur. of Mines, Bull. 177, pp. 149-151, 1919.

, and Vilas, is an oil- and gas-producing district which
venience may be designated the Altoona-Vilas field. It
tially a gas field, which, especially during the last fif-
ars, has contributed importantly to the production of
l in southeast Kansas. Gas was discovered here at a
rly date by the Isett-Erwin Oil and Gas Company, who
ne well which had an initial open-flow capacity of 20,-
cubic feet daily. Gas was not in demand at the time,
ttempts to find oil failed, the company disbanded. The
importance of the field dates from about 1906 or 1907,
newed activity in prospecting resulted in the develop-
f a number of remarkably good gas wells. Some of
ve had an initial open-flow capacity of more than 30,-
cubic feet per day. At present there are a few small
s, some near Altoona, others in the vicinity of Vilas,
quantity of oil obtained is not large. The production is
from the Cherokee shale. The relation of the occur-
of oil and gas in the Altoona-Vilas field to geological
e has not been determined by the Survey.

'redonia field. The area included in the Fredonia field
es the oil- and gas-producing territory in the vicinity
ity of Fredonia, extending east and southeast some five
niles toward Altoona and Neodesha. There is no evi-
arply defined line of division between this and the
ar the latter towns, and the designation is hence largely
onvenience. Both oil and gas are obtained in the Fre-
eld, production of gas being somewhat the more im-
. At least three oil and gas sands have been developed.
er sand, found at a depth of 350 to 500 feet, yields gas.
f the wells producing from this horizon have a daily
w capacity ranging from 1,000,000 to 3,000,000 cubic
n the fall of 1919 Stryker and Ladow developed a small
this sand, about five miles south of Fredonia. The gas
nd at 380 feet and the initial test showed nearly 1,500,-
ic feet open flow. Three gas wells were brought in, and
donia Gas Company shortly laid a line from these wells
lonia. The second sand, which has long been an im-
oil producer, is encountered at a depth of 750 to 900
may be correlated tentatively with the Peru or Weiser
Chautauqua and Montgomery county fields. The ini-

tial production of wells in this sand has in some cases been
high as 150 barrels per day, but this has usually been due to
unusually heavy charge of nitroglycerine. The yield of su
wells commonly declines within a month to 15 to 20 barre
The third sand belongs to the Cherokee shale and varies
depth from 1,000 to 1,150 feet. This is probably the sand fr
which the excellent gas wells in the vicinity of New Alba
five miles west of Fredonia, have produced. Two typical we
in the Fredonia field are represented on Plate IV, Nos. 11 a
12.

Subsurface exploration south of Fredonia has determin
the presence of a buried ridge of Mississippian limestone,
as it is called by the drillers, a "Mississippi lime structur
It is highly probable that this ridge represents the results
pre-Pennsylvanian erosion, and our present knowledge of
Mississippian in this region would not warrant a test of t
older series.

The Benedict-Buffalo field. North central Wilson county,
cluding the territory about the towns of Guilford, Benedi
Rest, Roper and Buffalo, has been a region of oil and gas dev
opment since 1900. The area, which may be called the Be
dict-Buffalo field, adjoins the Fredonia and Altoona-Vilas fie
on the south and southeast, and extends northward into sou
ern Woodson county. The earliest development was just sou
of Benedict, near Verdigris river. For a number of years
chief producing horizon was an 800-foot sand, which yiel
small but long-lived oil wells. In 1917 and 1918 the Dixie
and Gas Company drilled to a deeper sand, which was thou
to be equivalent to the Bartlesville horizon. In sections 22 a
23, township 28 south, range 15 east, a number of oil wells w
an initial production of 100 to 200 barrels per day have recen
been drilled. The settled production of these ranges from 30
40 barrels a day. The record of new wells drilled in Wil
county, which has been maintained since 1904, is as follows

able showing new wells completed in Wilson county, 1904 to 1919, inclusive.[10]

Year.	*Oil.*	*Gas.*	*Dry.*	*Total.*
1904	170	..	41	211
1905	36	24	16	76
1906	7	48	26	81
1907	...	47	10	57
1908	...	66	21	87
1909	...	89	24	113
1910	1	80	27	108
1911	2	65	27	94
1912	18	86	52	156
1913	40	54	45	139
1914	27	12	20	59
1915	6	13	4	23
1916	63	3	2	68
1917	137	21	22	180
1918	251	22	28	301
1919	158	12	33	203

The total and average initial production of these wells since 1 is as follows:

able showing total and average initial production of wells in Wilson county, 1911 to 1919, inclusive.

Year.	*Total initial production, barrels.*	*Average initial production, barrels.*
1911	35	17.5
1912	255	14.2
1913	342	8.6
1914	268	9.9
1915	35	5.8
1916	365	8.1
1917	1,596	11.6
1918	2,452	9.7
1919	2,719	17.2

The following table shows the amount of new production by nths for Wilson county since January, 1916.[11]

le showing new production in Wilson county by months, 1916-1919 inclusive, in barrels.

	1916.	*1917.*	*1918.*	*1919.*
January	...	35	91	120
February	...	80	153	142
March	...	80	167	87
April	45	48	168	229
May	80	58	348	542
June	50	153	251	368
July	...	331	170	210
August	...	65	130	395
September	45	289	371	148
October	20	344	290	349
November	70	60	125	124
December	55	53	188	5
Totals	365	1,569	2,542	2,719

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10. Data from Mineral resources of the United States, U. S. Geol. Survey, and trade nals.

11. Data compiled from monthly field summaries of the Oil and Gas Journal.

MONTGOMERY COUNTY.

Introduction. Montgomery county has long held a positi as one of the most important of the oil- and gas-producing are in Kansas. As indicated in a preceding paragraph, it was o of the first counties to report commercial production of the invaluable fuels, and in the period before the discovery of t rich Butler county pools it contributed very largely to the pr duction total of the state. Originally centering about a fe discovery districts, the county has now been so widely d veloped that the wells in one region are almost continuous wi those in another. Division of the producing territory in separate fields, especially in the southern part of the county, somewhat arbitrary. However, in part as a recognition the earlier districts, and in part as a convenient basis for t present description, the following oil and gas fields may identified: (1) Bolton, (2) Wayside-Havana, (3) Indepen ence, (4) Tyro, (5) Caney, (6) Coffeyville, (7) Cherryval (8) Elk City, and (9) Larimer-Sycamore. The distributi of oil and gas wells, dry and abandoned holes, so far as da are available, in these fields, is shown on plate III.

Gas is mainly produced in the Elk City field, the north a south Independence fields, the northeast part of the Cherr vale field, and in the Coffeyville field. Wells with an initi open-flow daily capacity up to 86,000,000 cubic feet have bee drilled, and large production from the county has been mai tained for many years. The older fields, such as that near I dependence, are largely exhausted and many wells have bee abandoned.

Oil production is obtained mainly from the fields on t southwest part of the county, Bolton, Wayside-Havana, Cane and Tyro, and in part from the Coffeyville, Cherryvale an Larimer-Sycamore fields. Wells with an initial daily capacit of more than 1,000 barrels have been drilled in a number places, but in most instances it is much less. The averag initial daily production for the county has been 10 to 20 barrel Some wells in the southwest fields have yielded 100 to 25 barrels settled production. Most of the “pumpers” do n produce more than 3 to 5 barrels daily. The oil ranges i quality from a heavy-grade specific gravity of about 22° Baum to a good paraffin oil of about 38° or 39° Baumé. The better o lighter oils are found in the central west and southwest part field, Cowley county.

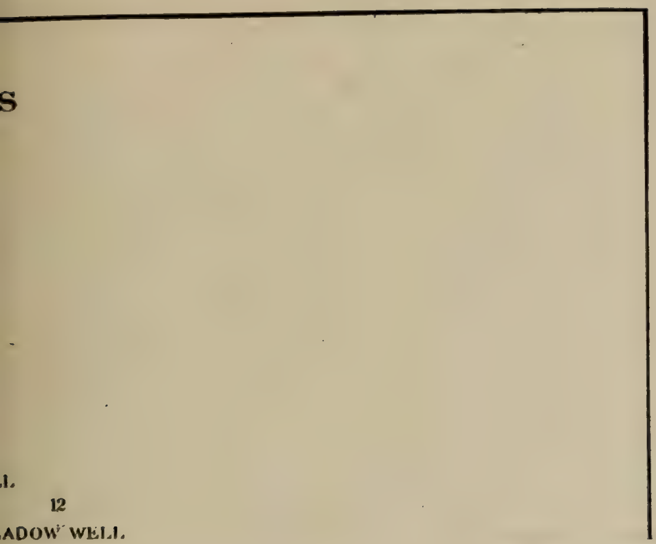

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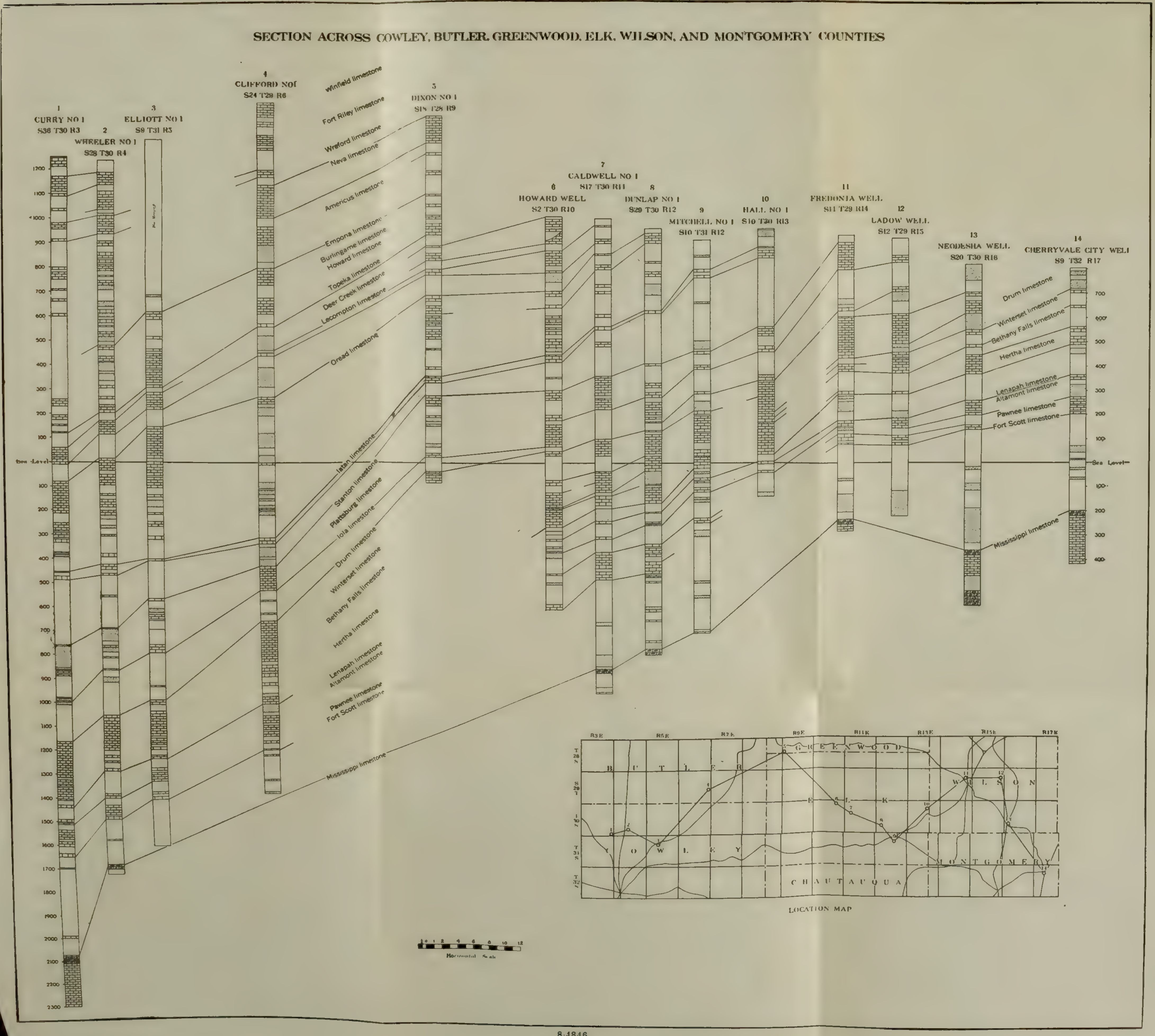
PLATE IV.

Geologic cross section of correlated well records from Cherryvale, Montgomery county, to a point ten miles north of Winfield, Cowley county.



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he county, the poorer grades being reported from south of
ependence and in the east part of the county.

. considerable number of new wells have been drilled each
r, the large proportion of which have been oil wells. More
ı 900 new wells were drilled in 1914 and in both 1913 and
5 the number was in excess of 860. Since the war the
culty of getting casing has retarded development, but it
 be anticipated that with a return to more normal condi-
s the large demand for petroleum products will bring re-
ed activity to Montgomery county fields.

he Bolton field. The important oil-producing area just
h of the town of Bolton, about six miles southwest of In-
endence, is known as the Bolton field. The first noteworthy
lopment here was in 1901, when a number of good gas
s were drilled in. The first oil well was drilled by McBride
 Bloom in the southwest quarter of section 18, township
outh, range 15 east, on the Jeff Bolt land. The drill en-
ıtered the oil sand at 1,180 feet, and at 1,195 passed from
l to shale. The initial production of this well was approxi-
ely forty barrels per day.[12] In a short time a number of
wells had been drilled on the southeast quarter of section
each with an initial production exceeding 500 barrels daily.
e wells in the field have reported an initial daily produc-
 of as much as 1,000 barrels. The Standard Oil Company
pleted a pipe line from its Neodesha refinery to the Bolton
 in the fall of 1903, and for the next two or three years
 area was probably more active than any other in the Mid-
inent field. In 1904 the Bolton field contained over 200
lucing oil wells. At the present time the field is still pro-
ing, but new development is not active.

he Wayside-Havana field. This field lies in the western
 of Montgomery county, southwest of the Bolton field. It
prises several square miles on either side of the Santa Fe
road between the towns of Wayside and Havana. Pro-
ting extended into this territory from the Bolton field in
4. Both oil and gas were discovered and the field is still an
ortant producer. The oil is a high-grade paraffin oil with
ecific gravity of about 36° to 38° Baumé, and though the
luction per well is in very few cases more than about

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2. Haworth, E., Kans. Univ. Geol. Survey, Special report on oil and gas, vol. 9,
.

twenty-five barrels per day, the producing life of the wells very long. The gas wells have an initial open-flow capac of about two million to four million cubic feet daily, an init pressure of 265 pounds, and an average life of about five yea

The Stanton limestone is the surface formation over mu of the Wayside-Havana field. The position of the outcrop this limestone northwest of Wayside (see plate I) is stron indicative of a local elevation of the rock strata in this regi but the structure has not been surveyed in the field. As dicated by the structure map of the Independence quadran (plate II) the area northwest of Wayside, where are locat most of the oil wells of the field, is a broad structural flat terrace. However, the data on which this map is based hardly sufficiently precise to permit accurate determination the structural conditions in the field.

Production in the Wayside-Havana field appears to co from four different stratigraphic horizons. The upperm sand is the Wayside, which is found at an average depth about 600 feet. It is one of the best sands in southeast Kans from the standpoint of the long life of the wells produci from it. Approximately 125 feet below the Wayside is Weiser sand, which produces a heavier oil than the upper sa In stratigraphic position the Weiser appears to be equival to the Peru sand of Chautauqua county, but the Peru yie a much better grade of oil. The third horizon in the Waysi Havana field is the Bartlesville sand, which is found at a de of 1,100 feet or more. This sand contains oil chiefly. T deepest sand is doubtless the Burgess horizon.[13] Much of gas comes from this deep sand. Many of the wells in the fie produce from two or three sands at the same time.

The amount of gas marketed from the Havana district the Southwestern Gas Company of Independence is as follow

1915	534,191,000 cu. ft.
1916	912,609,000 cu. ft.
1917	396,485,000 cu. ft.
1918	202,904,000 cu. ft.
1919 (to October)	15,424,000 cu. ft.

The average rock pressure of seventeen gas wells in Havana district, on August 10, 1917, was sixty-five pounds square inch.

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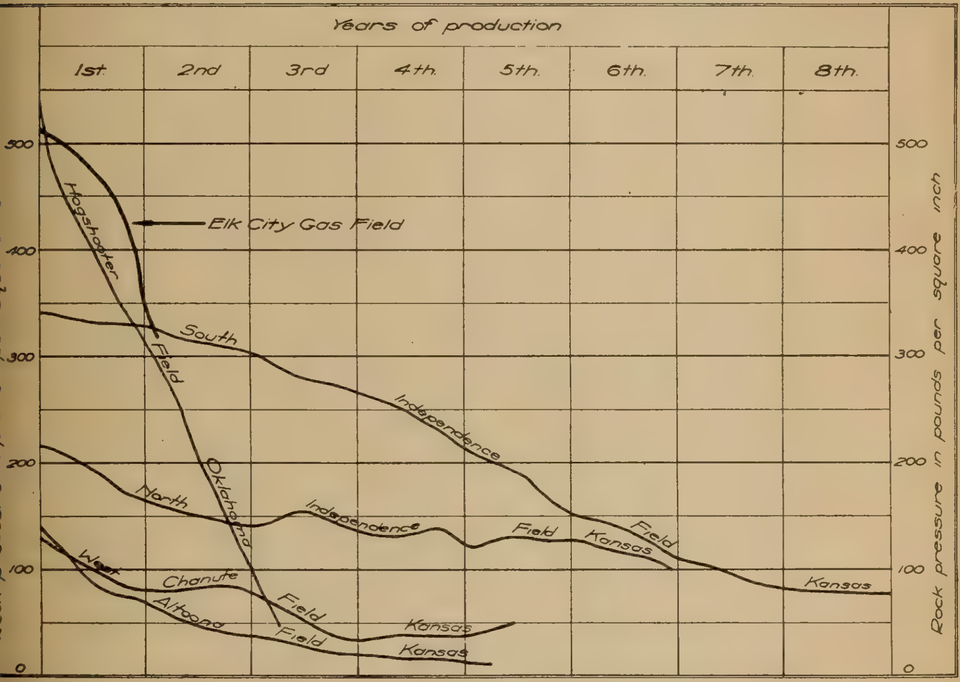
[13] Moore, Raymond C., and Haynes, Winthrop P., Kans. Geol. Survey, Bull. p. 342, 1917.

The Independence field. This field, comprising the territory
ainly south of the city of Independence approximately to
fferson, is a gas-producing district. Development began in
03 and 1904, when a number of gas wells with initial open-
w capacity ranging from twelve million to thirty-seven mil-
n cubic feet per day were brought in. In 1904 it is re-
rted[14] that the combined open-flow capacity of all the wells
the field then producing was about 700,000,000 cubic feet.
r a number of years the Independence gas field was not only
e most important in Montgomery county, but one of the best
the state. The apparently unlimited supply of cheap natural



URE 3.—Diagram showing the comparative decline in rock pressure in important southeast Kansas and Oklahoma gas fields.

s brought many industries to Independence, Cherryvale and
ffeyville. The population of these and other cities of eastern
ansas used the gas for domestic purposes and the numerous
dustrial consumers used it in their plants, but in spite of the
ormous quantity of gas consumed, the supply diminished
ly gradually. The decline of the pressure in the Independ-
ce field is shown in figure 3.

At the present time very many of the wells have "gone to
ater" and the rock pressure has declined to less than 100
unds. Gas is still produced, but not in sufficient quantity to

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[14] Haworth, E., loc cit., p. 37.

supply even the needs of the immediate vicinity. Gas is in
ported from the Oklahoma fields for consumption in parts c
Montgomery county. It is, of course, well recognized by a
who are familiar with the production of natural gas that th
extremely valuable fuel is not an inexhaustible resource. Th
wise conservation of our remaining supply is a vital considera
tion, not only for the benefits to the present generation, but t
the future population of the state. Notwithstanding the im
portance of industries which are using natural gas, the con
sumption of large quantities of gas at low rates in industria
plants diminishes the available supply for domestic use to suc
a degree that consideration may well be directed to the problem
of future supply for domestic use. With an inevitable declin
of natural gas production in the Midcontinent fields, the do
mestic consumer may anticipate an increase of cost which wi
make the price of the gas seem prohibitive. Eventually th
supply will be gone. It is possible that some new gas wells ma
be drilled in parts of the Independence field, but for the mos
part the field is practically exhausted.

The Independence field is located on the nearly level shal
area between the escarpments of the Drum and Stanton lime
stones (plate I). The structure has not been determined b
field surveys but a generalized representation of the structure
in so far as determinable from the Independence quadrangl
geological map of the United States Geological Survey, is in
dicated in plate II. This shows a structurally high area cross
ing the city of Independence in a northeast-southwest direc
tion and a slight depression south of Independence. This doe
not, apparently, follow the distribution of production, for ga
has not been developed northeast of Independence and ther
have been numerous good gas wells south of the town in th
area indicated as structurally lower than the surrounding ter
ritory. A determination of the structure in the field from
study of the sand records and from field work is desirable bu
has not been accomplished by the Geological Survey.

The producing sands in the Independence field are found a
average depths of about 700 and 1100 feet. They are probabl
the Weiser and Bartlesville sands.

The Tyro field. An area of oil and gas production near th
Oklahoma state line adjacent to the town of Tyro, on the Mis
souri Pacific railroad, is known as the Tyro field.

he discovery well in this field was drilled during the winter 903-'04, about 200 yards east of the railway station in Tyro. ring the following year development extended southward one of the best wells in the field was brought in on a lease ection 16, township 35 south, range 15 east, within 100 feet he Oklahoma boundary.[15] The producing sands in the Tyro rict are found at depths of about 1,000 and 1,300 feet.

he Caney field. Oil and gas production in the extreme theast corner of Montgomery county in the vicinity of the n of Caney may be included in the Caney field. Gas was overed northwest of Caney in 1901 in a sand encountered a depth of 1,480 feet. The well had an initial open-flow acity of 14,500,000 cubic feet daily, under 660 pounds rock ssure.[16] The producing sands in the vicinity of Caney correspond to those found at Wayside and Havana. Much of the comes from the Burgess horizon, found at a depth of 1,660 . Many of the gas wells have an initial capacity of 30,000,- cubic feet, under 600 pounds rock pressure.

he Coffeyville field. The Coffeyville field, comprising the itory about the town of Coffeyville, and extending several es west, northwest and northeast, is one of the oldest oil- gas-producing districts in southeastern Kansas. Origi-ly it was exclusively a gas field, no attention being paid to The first wells were very shallow, only 350 to 400 feet p, and because of the light rock pressure were soon ex-isted. In a few years, however, sands at depths of 600 and feet were developed. Oil production has been obtained in ious parts of the Coffeyville field. The wells are small and nost cases do not have a settled production of more than ten rels. Tests of the oil which have been reported[17] show a cific gravity ranging from 28° to 34° Baumé. The oil has a affin base.

he Cherryvale field. The Cherryvale field includes the area oil and gas production in the northeast corner of Mont-nery county and extending into Labette county. Gas was t developed in the field by the Cherryvale Gas Company and Edgar Zinc Company. The gas is now practically ex-

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[5] Schrader, F. C., and Haworth, E., U. S. Geol. Survey, Economic geology of In-ndence quadrangle, Bull. 296, p. 22, 1906.

[6] Haworth, E., Kans. Geol. Survey, Min. resources of Kansas, p. 56, 1900-01.

[7] Day, David T., Petroleum, U. S. Geol. Survey, Mineral resources of the United es, 1913, pt. II, pp. 1191-8.

hausted, the local factories being supplied with gas from th Elk City field. Oil was found northwest of Cherryvale in 190 many of the wells reporting an initial production of 50 to 10 barrels per day. The chief producing sand is found at a dept of 700 to 800 feet in the upper part of the Cherokee shale. Th record of a typical well in the Cherryvale field is shown o plate IV, well No. 14. The pool directly north of Cherryval in September, 1920, contained 128 producing oil wells.

In August, 1920, a new oil pool was discovered about fou teen miles northeast of Cherryvale, near the town of More head, in Neosho county. Twenty-six feet of sand was encour tered at 700 feet, and the initial production of the first we was slightly over fifty barrels per day.

The Elk City gas field. In November, 1917, the Oliver O Company drilled a well in the northwest quarter of section 3 township 31, range 13, directly west of Elk City. The drill er countered the Bartlesville sand at 1,360 feet, and after bein shot with a heavy charge of nitroglycerine produced over 10 barrels daily. The well was soon drowned by salt water, an although additional wells were drilled, the total productio from this section was of little importance. Subsequent de velopments have shown that these wells were on the edge o the Elk City gas field, which is at present the most importan gas-producing area in southeast Kansas. The discovery we in the gas field was drilled by the Elk Valley Syndicate on th Simmons farm, in the northeast quarter of section 27, town ship 31 south, range 13 east, in Elk county. The initial oper flow capacity of this well was 10,000,000 cubic feet under rock pressure of 520 pounds. Development immediately ex tended in all directions, and it was soon found that section 2 in Montgomery county was equally as good as the area in El county. The producing area in the Elk City field is slightl more than three and one-half square miles, and at present con tains about fifty producing wells. These wells range in oper flow capacity from 1,500,000 to 86,000,000 cubic feet of ga daily. The field is at present controlled by the Southwester Gas Company of Independence and the Hale Oil and Gas Com pany of Neodesha.[18]

Larimer-Sycamore field. During May and June, 1920, small oil pool was developed along the Missouri Pacific rai between Larimer and Sycamore, due north of Independ- e. Up to the middle of June about fifteen wells had been led, all of which were productive. What is believed to be Bartlesville sand was encountered at 1,000 to 1,070 feet, a thickness varying from 18 to 50 feet. It is reported that wells pump about 60 barrels daily after being shot with oglycerine. The oil tests 38° Baumé gravity.[19]

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[18] Boughton, Charles W., Elk City gas field, Kans. Geol. Survey, Bull. 5, 1920.

ecords of development in Montgomery county. The num- of wells drilled in Montgomery county since 1904, when plete data were gathered for the first time, is as follows:

Table showing new wells drilled in Montgomery county, 1904 to 1919, inclusive.

Year.	*Oil.*	*Gas.*	*Dry.*	*Total.*
1904	715	. .	113	828
1905	104	89	40	233
1906	60	88	21	169
1907	21	31	4	56
1908	1	79	17	97
1909	5	100	22	127
1910	16	56	7	79
1911	60	36	22	118
1912	202	116	47	365
1913	602	173	92	867
1914	691	137	75	903
1915	201	129	49	379
1916	778	34	48	860
1917	336	27	78	441
1918	334	28	95	457
1919	182	41	47	270

he following table shows the amount of new production, by ths, for Montgomery county since January 1, 1916.

ble showing new production in Montgomery county by months, 1916 to 1919, inclusive, in barrels.

	1916.	*1917.*	*1918.*	*1919.*
January	620	320	269	75
February	691	328	61	219
March	795	523	334	37
April	841	276	337	102
May	1,212	597	427	133
June	1,535	427	627	106
July	1,259	705	288	140
August	821	403	304	136
September	905	235	230	512
October	365	396	114	513
November	695	275	259	334
December	465	389	81	212
Totals	10,204	4,874	3,331	2,519

). Oil and Gas Journal, June 11, 1920, p. 46.

REFINERIES.

Six active refineries are located in Wilson and Montgome counties, one of them, the Standard Oil Company refinery Neodesha, being much the largest, as it is the oldest in Kans Not only is most of the oil produced in the local fields treated these refineries, but much of the production from adjace counties in Kansas and northern Oklahoma. The following l shows the distribution, date of construction and the daily pacity of these refineries.

Refineries in Wilson and Montgomery counties.

Company and location.	*Year built.*	*Daily capac bbls.*
Empire Refineries, Inc., Independence	1919	2,500
Kansas Oil Refining Company, Coffeyville	1906	1,800
National Refining Company, Coffeyville	1907	4,000
Sinclair Refining Company, Coffeyville	1919	5,000
Standard Oil Company (Kansas), Neodesha	1897	12,000
Uncle Sam Oil Company, Cherryvale	1906	1,500
Wright Producing and Refining Company, Cherryvale	1917	Idle

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STATE GEOLOGICAL SURVEY *of* KANSAS
RAYMOND C. MOORE, *State Geologist*

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BULLETIN 8

The Economic Geology of the Arkansas City District

By EMMETT R. ELLEDGE

Clay and Shale Resources in the Vicinity of Arkansas City, Kansas

By PAUL TEETOR

In coöperation with the Chamber of Commerce,
Arkansas City, Kan.

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PRINTED BY KANSAS STATE PRINTING PLANT
B. P. WALKER, STATE PRINTER
TOPEKA 1921
9-1243

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BY PAUL TEETOR

In coöperation with the Chamber of Commerce,
Arkansas City, Kan.

Printed by authority of the State of Kansas

PRINTED BY KANSAS STATE PRINTING PLANT
B. P. WALKER, STATE PRINTER
TOPEKA 1921
9-1243

Publications of the State Geological Survey are distributed from Lawrence, Kansas.

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CONTENTS.

OMIC GEOLOGY OF THE ARKANSAS CITY DISTRICT:

BY EMMETT R. ELLEDGE.

PAGE

ntroduction 5
- Location 5
- Acknowledgments 7
- The environment of Arkansas City 7
- Development of the Arkansas City district 9

eology 11
- Rocks exposed in the Arkansas City district 13
  - Chase formation 14
  - Marion formation 16
  - Wellington formation 18
  - Quaternary deposits 19
- Concealed rocks in the Arkansas City district 19

conomic geology 22
- Oil and gas 22
  - Development 22
  - Structure 26
  - Refineries 31
- Clay 31
- Road materials 33
  - Samples 33
- Cement 34
- Building stone 35
- Water supply 35

AND SHALE RESOURCES IN THE VICINITY OF ARKANSAS CITY:

BY PAUL TEETOR.

ntroduction 38
- Properties and testing of clays 38

rkansas City clays 39
- Pearl shale 40
- Enterprise shale 42
- Doyle shale 45

ILLUSTRATIONS.

PLATE.

I. Summit street, Arkansas City, looking north.
II. Views in Arkansas City business section.
III. Geological and production map of Cowley county, Kansas.
IV. *Above:* Outcrop of Herington limestone north of Arkansas C *Below:* Exposure of Fort Riley limestone in quarry in 1, T. 35 S., R. 4 E.
V. *Left:* Quarry in Fort Riley limestone north of Silverdale. *Rig* Exposure of Winfield limestone at Horseshoe Hill.
VI. *Left:* Gravel washer north of Silverdale. *Right:* Pleistoc gravel deposit north of Silverdale.
VII. Oil well in sec. 16, T. 29 N., R. 3 E., Kay county, Oklahoma, miles southeast of Arkansas City, showing also the outcro the Winfield limestone.
VIII. Structure map of area east of Arkansas City, Cowley cou Kansas.
IX. The Empire natural-gas gasoline refinery at Arkansas City.
X. *Above:* Milliken oil refinery. *Below:* Kanotex oil refinery.
XI. View of the flood plain of Arkansas river, looking west tow Arkansas City.
XII. Burning shrinkage-temperature curves of Arkansas City cl
XIII. Porosity-temperature curves of Arkansas City clays.

FIGURE.

1. Location map of the Arkansas City district.
2. Map showing location of Arkansas City with reference to the oil gas fields of Kansas and Oklahoma.

e Economic Geology of the Arkansas City District.

By EMMETT L. ELLEDGE.

INTRODUCTION.

The biggest town of its size in the United States," re-·ked my friend in the Pullman smoking compartment as rolled swiftly past the green fields of a part of central ısas, "is Arkansas City, down near the south line of the e. When you talk about wide-awake business 'go,' pro-ssivêness, and all the other things that make a town worth le—clean, paved streets, fine schools and churches and nice ıes—you may put our city right alongside of any of them in good old U. S. A., and I've been a long way east and west, "

'or the benefit of those who live outside of Kansas and ahoma, and those who may never have chanced to meet an ansas Citian, it may be mentioned that their headquarters nd there are 11,253 of them reported in the 1920 census— ocated just three miles from the Oklahoma state line in thwestern Cowley county, which is about one-third of the e's length east and west from the east Kansas boundary. e figure 1.) It is thus located in the midst of a prosperous growingly wealthy part of the great Midcontinent region ich has witnessed so rapid a development in the last few ades.

t the request and with the coöperation of the Chamber of nmerce of Arkansas City, the State Geological Survey has de a special examination of the country immediately ad-ent to Arkansas City in order to determine in advance, so as possible, the natural resources which may contribute ther to the development of the city, and to indicate the itations which may exist in the possibilities of utilization certain of the local resources. This bulletin records the re-ts of these investigations and represents a type of com-nity study which, it is believed, may advantageously be con-

ducted in many parts of our state. It may be pointed out
this connection that definite scientific information along a
line affecting community or state interests is very valuab
even though in some particulars it may be negative; for it
of course, quite as important to save money which might
uselessly invested and to avoid failures, as it is to call att

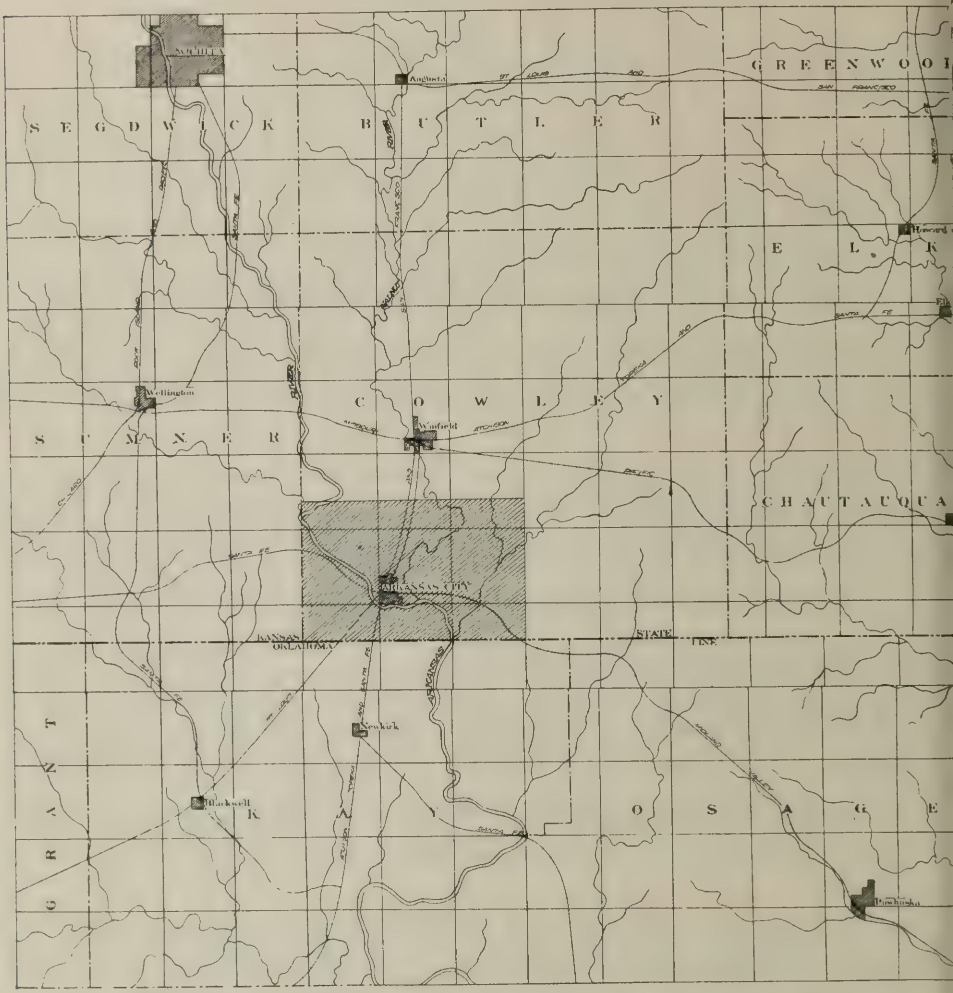


FIGURE 1. Location map of the Arkansas City district.

tion to possible resources, the quality, quantity and ex
nature of which has not previously been known.

The area examined especially in the study of the Arkan
City district includes approximately 220 square miles, the lo
tion of which is shown on the index map (figure 1.) The f
work was done by the writer, assisted by Mr. Lawrence H
between June 10 and August 20, 1920. A considerable a
was mapped with plane table and telescopic alidade in orde

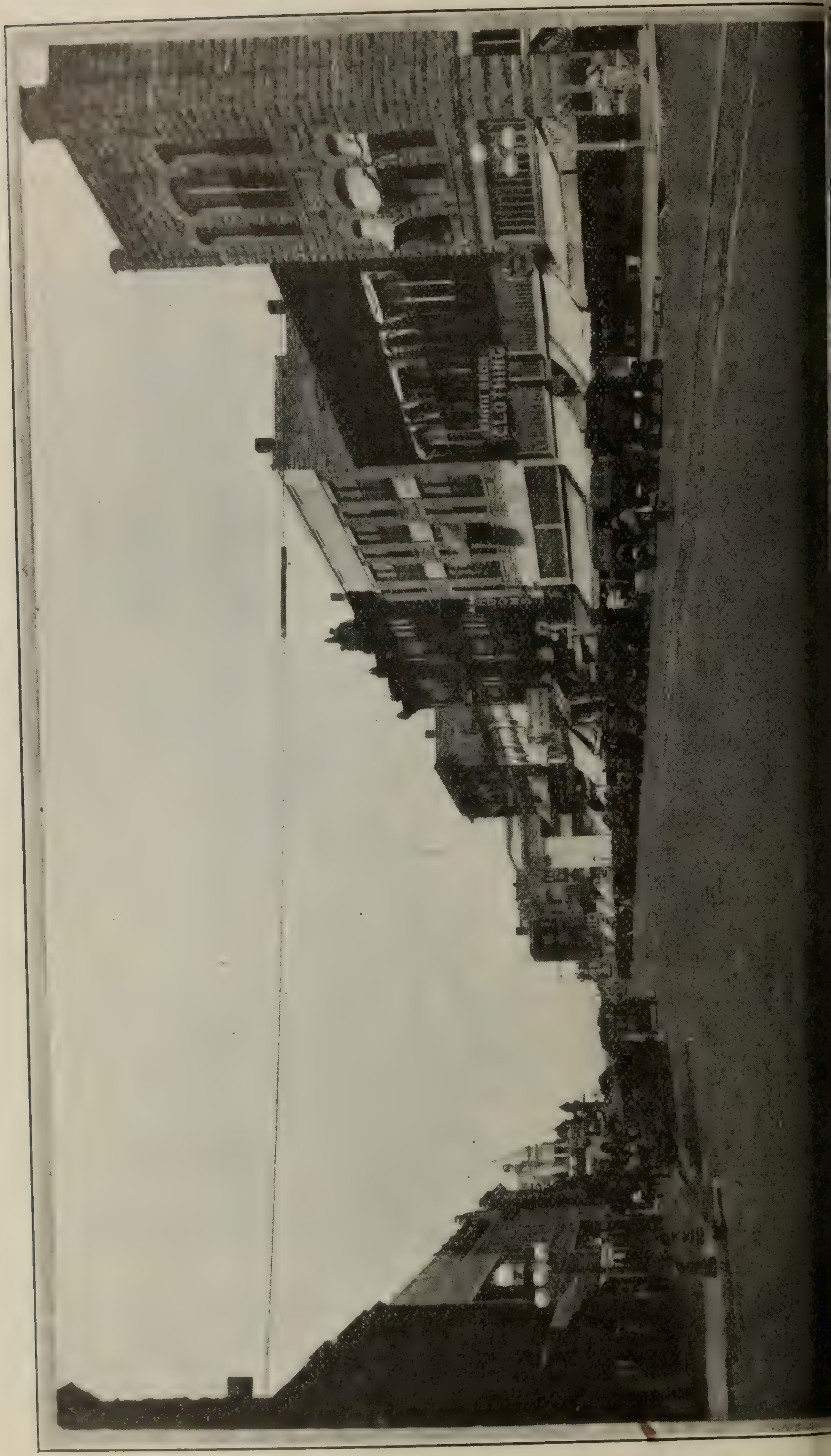
rmine somewhat precisely the local structure of the rocks the possibilities of oil and gas development. All of the was examined with reference to other resources, such as materials, sand and gravel deposits, brick clays, and r materials of possible value. Special acknowledgment be made of the assistance of Mr. O. B. Seyster, secretary he Chamber of Commerce, for coöperation during the ress of the survey, and for information concerning the de- pment of the Arkansas City area; and to Mr. M. W. Baden, Vinfield, on the stratigraphy and general structural condi- s in this part of the state. The Survey is indebted to the ire Gas and Fuel Company for part of the information in compiling the geological map of Cowley county.

THE ENVIRONMENT OF ARKANSAS CITY.

e country about Arkansas City has a rolling topography, hief features of which are the rather abrupt escarpments ed by the outcrop of limestone beds, and the broad, level s in the valleys of Arkansas and Walnut rivers. The es- ment topography is controlled by moderately hard out- ping limestones, which weather less readily than the in- edded shales. Arkansas City is well located with reference pography, being situated on a nearly flat river terrace ed at the junction of Arkansas and Walnut rivers.

e largest stream is Arkansas river, which crosses the hwest corner of Cowley county from northwest to south- This stream, with Walnut river, which drains the area the north and empties into the Arkansas just east of nsas City, drains practically all the area under discussion. e southwest part of Cowley county contains many acres of valuable farm land, especially that in the valleys of the rivers crossing the area, and Arkansas City is an important strial center, so that the area is rather thickly populated. s which are most important are wheat, corn, alfalfa and . Some of the Arkansas river bottom land is considered cially adapted for apple growing, and there are a number e apple orchards within this area.

e of the important contributing factors in the development e agricultural resources of any area is the climate. Ac- ing to statistics compiled by the United States weather au, from observations made at Winfield, the average



precipitation in this area from 1894 to 1917, inclusive, 79 inches. The highest average for any month during riod was 5.11 inches, in June, and the lowest 0.99 inch, ary. For the twenty-year period ending with 1917 the annual temperature was 56.5 degrees Fahrenheit. The average was 33.1 degrees, in January, and the highest grees, in July. For this same period the average date earliest killing frost in the fall was October 19, and for killing frost in the spring was April 15.

EVELOPMENT OF THE ARKANSAS CITY DISTRICT.

pril 7, 1870, the town of Cresswell was founded on the site of Arkansas City, but only a few months later the vas changed to that by which the town is now known. located on relatively high land between Arkansas and rivers, this topographic location affording excellent drainage and immunity from danger of possible floods. ng the first fifteen years the greatest problem cong the town was transportation. All provisions had to ghted, first from Emporia and later from Wichita. Bethe years 1875 and 1879, when the coming of the railseemed impossible, the citizens considered the navigathe Arkansas river as a means of getting products to m the town, but the shallowness of the channel and the ce of numerous sand bars made this almost an impossi-

ugh the efforts of a few energetic citizens, the Santa road became an assured fact in 1885. Lots were given site of the station and $10,000 was contributed toward lding. These citizens were also instrumental in locating nta Fe shops in Arkansas City a few years later. Later issouri Pacific railroad built a line through Arkansas

than two years after the founding of the town a union building was erected. To-day the town boasts of some finest church buildings in the state. A public school was l in Arkansas City when as yet it was only a few weeks our years later a substantial brick building was erected med the First Ward school. The city now has four ward s, a fine high school and a junior high school. The

Plate II. Views in Arkansas City business section.

ent school plant is valued at $750,000, and the schools are ng the best in the state.

1885 the Land Improvement and Water Power Company pleted the canal connecting the Arkansas river northwest wn with the Walnut southeast of the city. For years this l furnished power for a number of manufacturing establnents, and at present is the source of power for the A. C. ing Company and for the electric-light plant.

ne same year saw the beginning of an important building in Arkansas City, and a number of attractive buildings e erected. The growth of the city was considerably ded, however, by the opening of the "strip" in Oklahoma, and panic of 1893 caused a cessation of plans for the town's lopment; but during the last few years growth has been more rapid than before. The growth in population since) has been 49 per cent. Since 1912 Arkansas City has been erned by a commission form of city government.

rkansas City is one of the important industrial centers of state. Four oil refineries are located here: the Milliken pany, the Kanotex, the National Oil Company, and the pire natural-gas gasoline plant. The charging capacity of e refineries combined is 12,100 barrels per day. The divi headquarters of the Santa Fe for south Kansas and north Oklahoma, and large shops, are important contributing ors to the growth and prosperity of the city. Two flour s, with a daily capacity of 2,400 barrels, are also located . Some of the other industries include a candy factory, eat-packing plant, and an ice plant.

GEOLOGY.

he rocks of Kansas, as classified on the basis of origin, be to the sedimentary group. Rocks of igneous origin have found in some deep wells, but do not outcrop at the sur within the boundaries of the state. Sedimentary rocks those composed of the transported fragments or particles lder rocks which have undergone disintegration. The chief ncies of transportation are water, wind and glaciers. Maals such as gravel, sand and clay are carried as solid parti, and after deposition may be consolidated to form conglomte, sandstone or shale. Other materials may be carried in ition and deposited to form limestone, salt or gypsum.

Sedimentary rocks are usually made up of beds or layers, called strata, which can easily be separated.

The rocks which appear at the surface in the state belong to the Mississippian, Pennsylvanian, Permian, Cretaceous and Tertiary geologic divisions, named in order from older to

Geologic section of the Kansas region.

SYSTEM.	Groups.	Formation.	Character of rocks.
Quaternary.	Recent.		Alluvium, dune sands.
	Pleistocene.	Wisconsin stage, Kansas stage.	Glacial deposits.
Unconformity.			
Tertiary.	Pliocene, Miocene.	Ogalalla.	Gravel, sand, clay.
Unconformity.			
Cretaceous.	Montana.	Pierre.	Shale.
	Colorado.	Niobrara, Benton.	Limestone, chalk, shale.
	Dakota.	Sandstone.	Sandstone, shale.
Unconformity.			
Comanchean.	Washita.	Kiowa, Cheyenne.	Sandstone, shale.
Unconformity.			
Permian.	Cimarron.	Greer, Woodward, Cave Creek, Enid.	"Red beds," sandstone, shale, dolomite, gypsum, salt.
	Big Blue.	Wellington, Marion, Chase, Council Grove.	Shale limestone.
Pennsylvanian.	Missouri.	Wabaunsee, Shawnee, Douglas, Lansing, Kansas City.	Limestone, shale, sandstone.
	Des Moines.	Marmaton, Cherokee.	Limestone, shale, sandstone.
Unconformity.			
Mississippian.	Chester. *Unconformity.*		
	Osage.	Warsaw, Keokuk, Burlington, Pierson.	Limestone.
	Kinderhook.		Limestone, shale.
Unconformity.			
*Ordovician.		Joachim, Jefferson City, Roubidoux.	Dolomite, sandstone, shale.
Unconformity.			
*Cambrian.		Gasconade, Proctor, Eminence, Potosi.	
Unconformity.			
*Pre-Cambrian.			Granite.

*Not exposed in Kansas.

TE GEOLOGICAL SURVEY
OF KANSAS

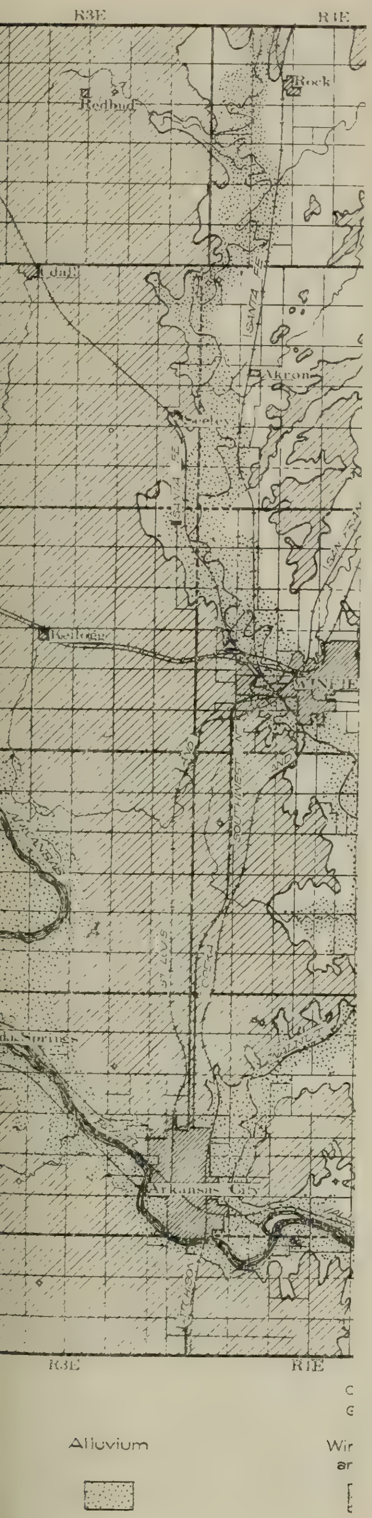


PLATE III. G

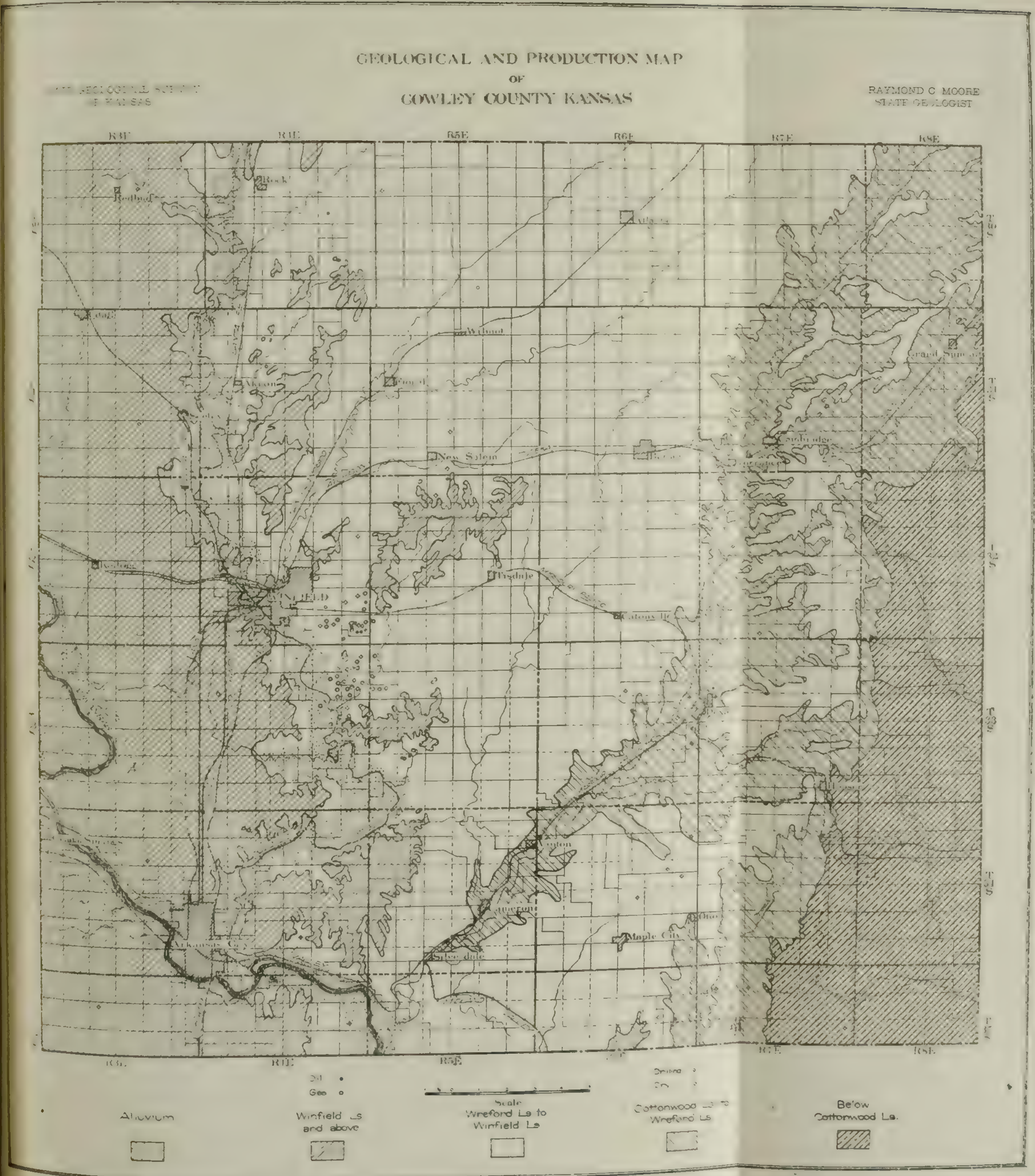


PLATE III. Geological and production map of Cowley county, Kansas.

ger. The older systems, of course, underlie the younger, h were laid down upon them. Sedimentary rocks of sys- older than the Mississippian are known to underlie the from records obtained in drilling deep wells, and wells ntral Kansas have encountered igneous rocks of pre-Cam- age. The accompanying table (page 12) gives the sub- ions of the various systems as recognized in Kansas.

ROCKS EXPOSED IN THE ARKANSAS CITY DISTRICT.

e rocks which are exposed in the Arkansas City district g to the lower group of the Permian system. Members ging to the Upper Pennsylvanian system outcrop in the rn half of Cowley county, but do not appear at the surface e area included in the Arkansas City district. The dis- tion of the formations which appear in Cowley county is n on plate III. The following table gives the divisions of 'ennsylvanian and Permian systems.

an system.
- imarron group.
- ig Blue group
  - Wellington formation (undifferentiated).
  - Marion formation.
    - Pearl shale.
    - Herington limestone.
    - Enterprise shale.
    - Luta limestone.
  - Chase formation.
    - Winfield limestone.
    - Doyle shale.
    - Fort Riley limestone.
    - Florence flint.
    - Matfield shale.
    - Wreford limestone.
  - Council Grove formation.
    - Garrison shale and limestone.
    - Cottonwood limestone.

ylvanian system.
- issouri group.
  - Wabaunsee formation.
    - Eskridge shale.
    - Neva limestone.
    - Elmdale shale.
    - Americus limestone.
    - Admire shale.
    - Emporia limestone.
    - Willard shale.
    - Burlingame limestone.
  - Shawnee formation.
  - Douglas formation.
  - Lansing formation.
  - Kansas City formation.
- 'es Moines group.
  - Marmaton formation.
  - Cherokee shale (undifferentiated).

Exposed in Arkansas City district.

Exposed in Cowley county.

As shown in the table, the rocks exposed in the Arkansas City district belong to the Chase, Marion and Wellington formations of the Big Blue group of the Permian. This group the lower division of the Permian, consists entirely of marine sediments, divided, in the order of their quantitative importance, into shale, limestone, and sandstone. These formations will be discussed in the order of their appearance as the area is crossed from east to west, or from oldest to youngest.

CHASE FORMATION.

Members belonging to the Chase formation are the oldes and lowest rocks, stratigraphically, which appear in the Arkansas City district, and occupy approximately the easter one-half of the area. (See plate III.) The formation contain a number of massive, cherty limestone members, which, on account of their resistance to erosion, form one of the mos prominent topographic features of central Kansas, the Flin Hills. The Chase formation has a total thickness of about 25 feet.

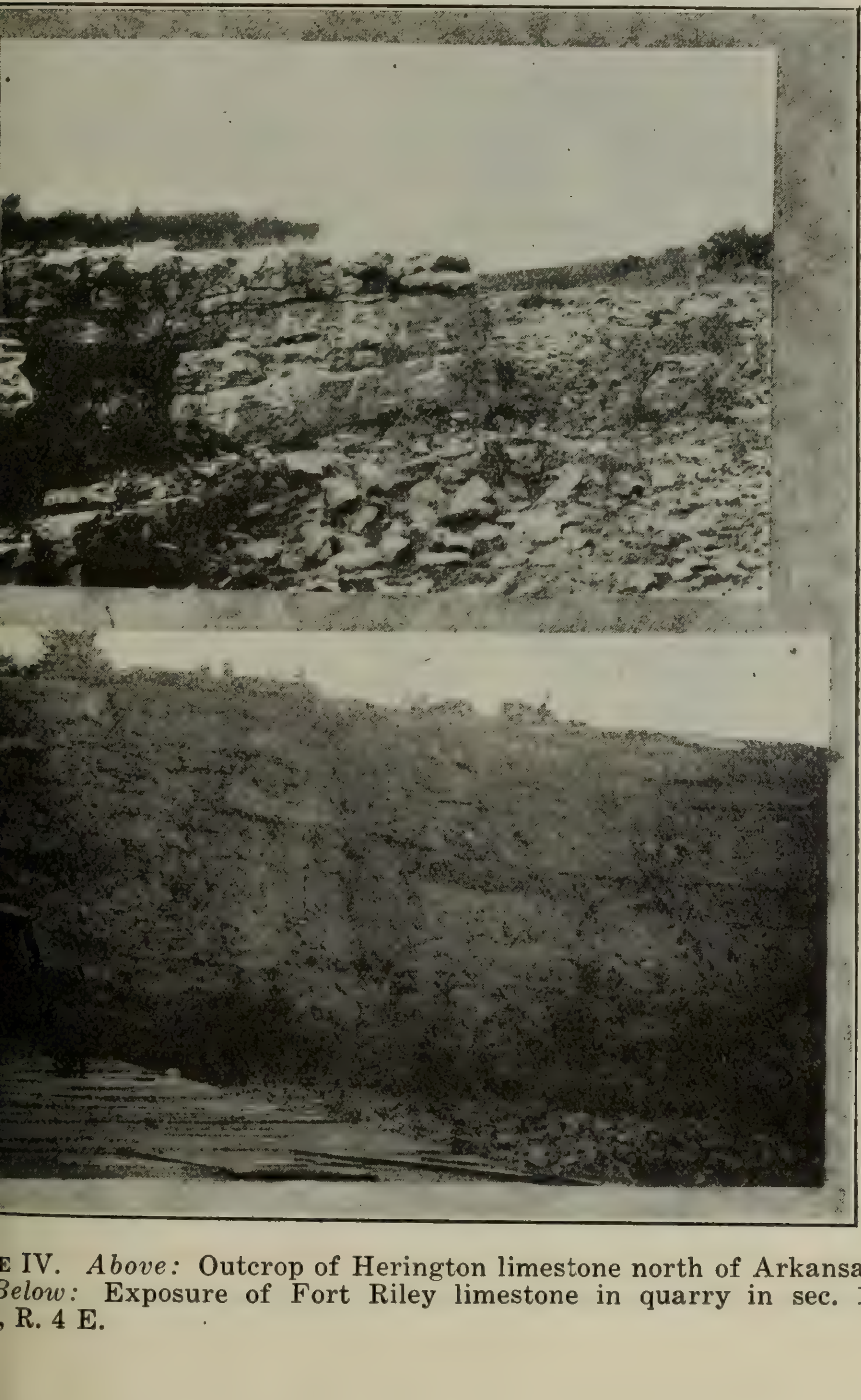
The lowest subdivision of the Chase formation is the Wreford limestone, consisting in its type locality of 35 to 50 fe of massive limestone and chert. The outcrop of the Wrefor forms a rather prominent escarpment across eastern Cowle county, and extends westward along Grouse creek to nea Silverdale in the eastern part of this area. In parts of southern Kansas the Wreford becomes imperfectly solidified ar weathers in places to a reddish-brown, very porous rock. T thickness of the Wreford in parts of Cowley county is not mo than 15 to 20 feet.

Overlying the Wreford is the Matfield shale member, whi includes from 60 to 70 feet of variously colored shales a thin, interbedded limestones. The outcrop at the surface not wide.

The Florence flint consists of about 20 feet of very flin limestone, a number of layers being composed wholly of fli The member is resistant to erosion, and with the overlyi Fort Riley limestone forms a prominent escarpment.

The Fort Riley limestone includes about 40 feet of massi buff limestone with thin, interbedded shaly strata in the upp part. Near the center of the member are one or two ve massive beds, which form a conspicuous bench at the outcr

rt Riley limestone and the Florence flint outcrop in the
as City district, the nearest exposure being in a large
about five miles east of town in sec. 1, T. 35 S., R 4 E.,
the Fort Riley measures 40 feet in thickness and con-
massive buff limestone, with a little shale in the upper
. (See plate IV.) The Florence flint is not so well ex-
but is recognizable immediately below the Fort Riley.



E IV. *Above:* Outcrop of Herington limestone north of Arkansas
elow: Exposure of Fort Riley limestone in quarry in sec. 1,
, R. 4 E.

Another good exposure of the Fort Riley is found in the qua about two miles north of Silverdale.

The Doyle shale member overlies the Fort Riley limestc and consists of variously colored shales, with thin, interbed shaly limestone beds. In its type area the Doyle shale is ab 60 feet thick, but is thinner in the Arkansas City district, thickness in some localities being less than 30 feet. I thicker in the northern part of the area, and contains rather persistent limestone bed near the center, which is ab a foot thick.

The Winfield limestone is the top member of the Chase mation. In areas farther north the Winfield is a very ch limestone, but in the vicinity of Arkansas City this cha teristic is not so prominent. In this area the member is a 15 feet thick. It has a very porous texture near the top, the upper portion is also fossiliferous, containing nume crinoid stems and brachipods. The Winfield ranges in from gray to yellow. It forms an easily traceable escarp throughout this area, and was used very largely in deter ing the rock structure of the area. The Winfield is typi exposed near Winfield, 15 miles north of Arkansas City, its outcrop extends entirely across Cowley county from r to south. (See plate III.) An excellent exposure ma seen about five miles east of Arkansas City at the top of is locally known as Horseshoe Hill. (See plate V.)

MARION FORMATION.

The Marion formation is clearly defined from the beds and below it. It lacks the cherty character of the Chase mation below, and is distinguished from the overlying ington formation by its limestone content, which is pract absent in the higher formation. The outcrop of the Mar characterized by broad, rather gentle slopes, in direct co to that of the Chase formation. The Marion formation total thickness of about 150 feet and has been divided four stratigraphic subdivisions.

Over a considerable portion of central Kansas the limestone forms the basal member of the Marion form It is well exposed in the vicinity of Marion and near H ton, where it is a cellular, soft, gray limestone about 1 thick. The member becomes much thinner to the south

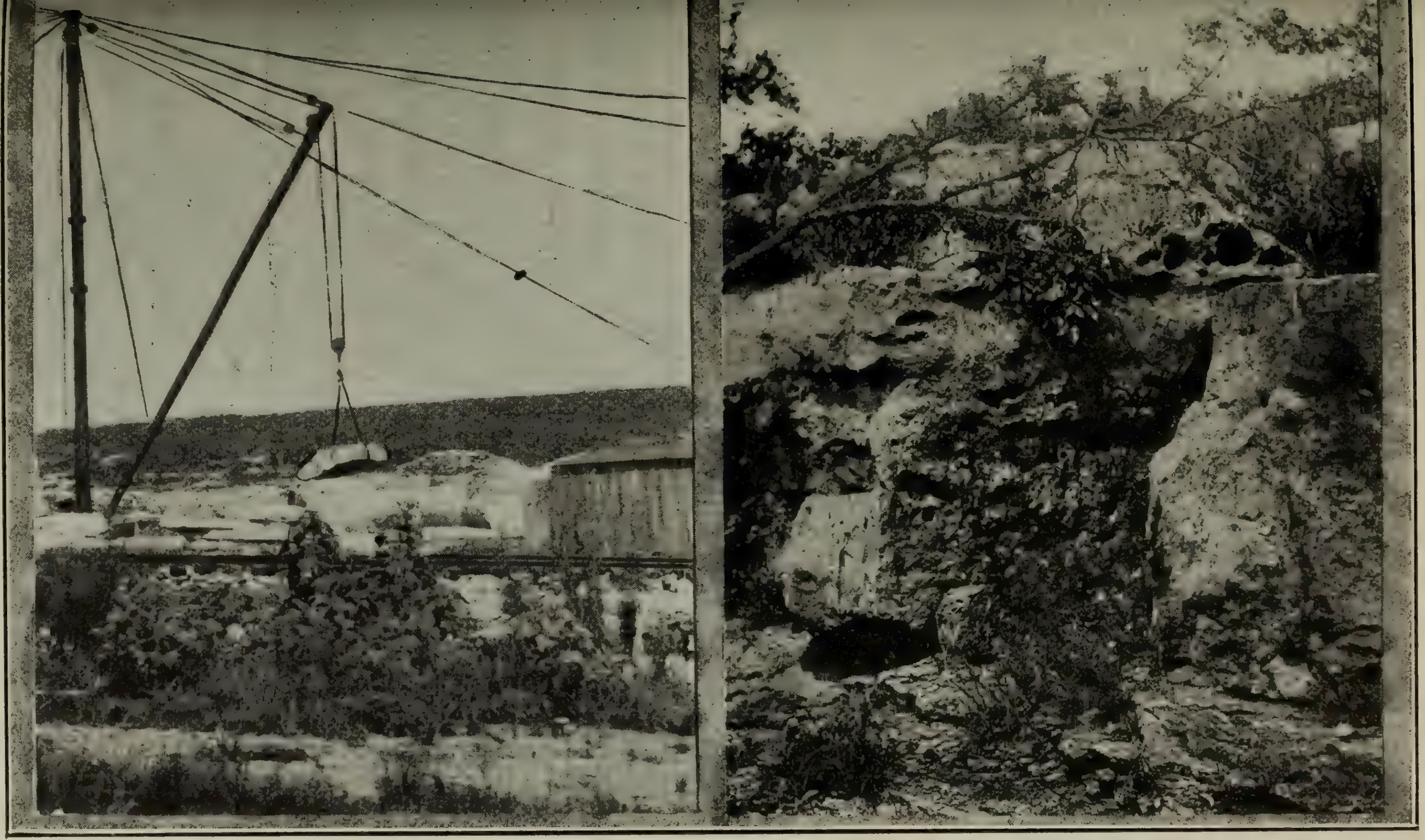


PLATE V. *Left:* Quarry in Fort Riley limestone north of Silverdale. *Right:* Exposure of Winfield limestone at Horseshoe Hill.

barely recognizable in the area about Arkansas City. In some places it is represented by two or three feet of soft, fossiliferous, gray limestone lying immediately above the Winfield, but it is not present over most of southern Cowley county.

The Enterprise shale member consists of variegated shale green, yellow and maroon in color. It has a thickness in the Arkansas City district of from 45 to 65 feet.

Succeeding the Enterprise shale is a buff to gray, massiv limestone, which is rather well exposed in the vicinity of Arkansas City. From typical exposures in the vicinity of Herington, this member has been named the Herington limestone As exposed about one mile north of Arkansas City, the Herington is about 8 to 10 feet thick, is rather massive, and in place is very sandy. (See plate IV.) A few miles south of Arkansas City, south of Arkansas river, the Herington consists o two limestone beds, separated by 12 to 15 feet of limy shale The lower limestone is about 3 feet thick, light gray in colo rather hard, and contains a few chert nodules. The uppe ledge is about 8 feet thick, buff to light gray in color, thi bedded, and is a good deal softer than the lower ledge.

A succession of green, blue and red shale, termed the Pea shale member, overlies the Herington limestone. On accour of the lack of resistance of the overlying members, outcrops c the Pearl shale are very uncommon. The thickness of th member is estimated to be 70 feet. There are a few more c less persistent limestone members in the upper portion of th Pearl shale, which mark the line of division between th Marion and Wellington formations. These beds have a rath porous texture and are not resistant to weathering, and co sequently do not form prominent escarpments.

WELLINGTON FORMATION.

The Wellington formation is the highest formation whi is exposed in the Arkansas City district, the lower part of th formation outcropping in the western part of the area near t Sumner county line. The Wellington consists of a thick su cession of blue, gray and yellow shales, with a very few no persistent limestone beds. The total thickness of the Wellin ton is estimated to be over 500 feet, but the thickness of t portion exposed in this area is much less. Owing to the la of any distinct stratigraphic marker between the Wellingt arion formations, the exact eastern boundary of the gton has not been determined.

QUATERNARY DEPOSITS.

ddition to the stratified rocks discussed, there are in rea unconsolidated sediments belonging to the Quaterystem. These deposits are the river alluvium in the of the Arkansas and Walnut rivers and at least one deposit of Pleistocene age. This deposit is located 3 north of Silverdale and is a Pleistocene river deposit. sists largely of a chert gravel, probably having its origin cherty members of the Chase formation. The deposit several acres of ground and is about 8 feet thick. (See VI.)

CEALED ROCKS IN THE ARKANSAS CITY DISTRICT.[1]

rmation concerning the rocks which underlie the Arkanty district, but which do not appear at the surface anyin the area examined in this survey, may be obtained wo sources, one from well records, and the other from ations made at the outcrops outside the area. From a of well logs it is known that the lower formations of the an system and the Pennsylvanian system of Kansas unall of southwest Cowley county. A number of wells een drilled into the Mississippian, so that at least a part system is present. On account of the general west dip rock strata in eastern Kansas, these formations which esent beneath the surface in the Arkansas City district p farther east where the overlying rocks have been l.

well were drilled near Arkansas City, starting in the ld limestone member, it would pass through about 200 f limestone and shale belonging to the Chase formation, outcrops in the area east of Arkansas City. The next formation which would be encountered is the Council formation, the basal division of the Permian. The ge total thickness of the Council Grove is about 150 feet. sists of an upper member of shale and thin, interbedded ones, and a lower, resistant limestone member at the After passing through the Council Grove formation the

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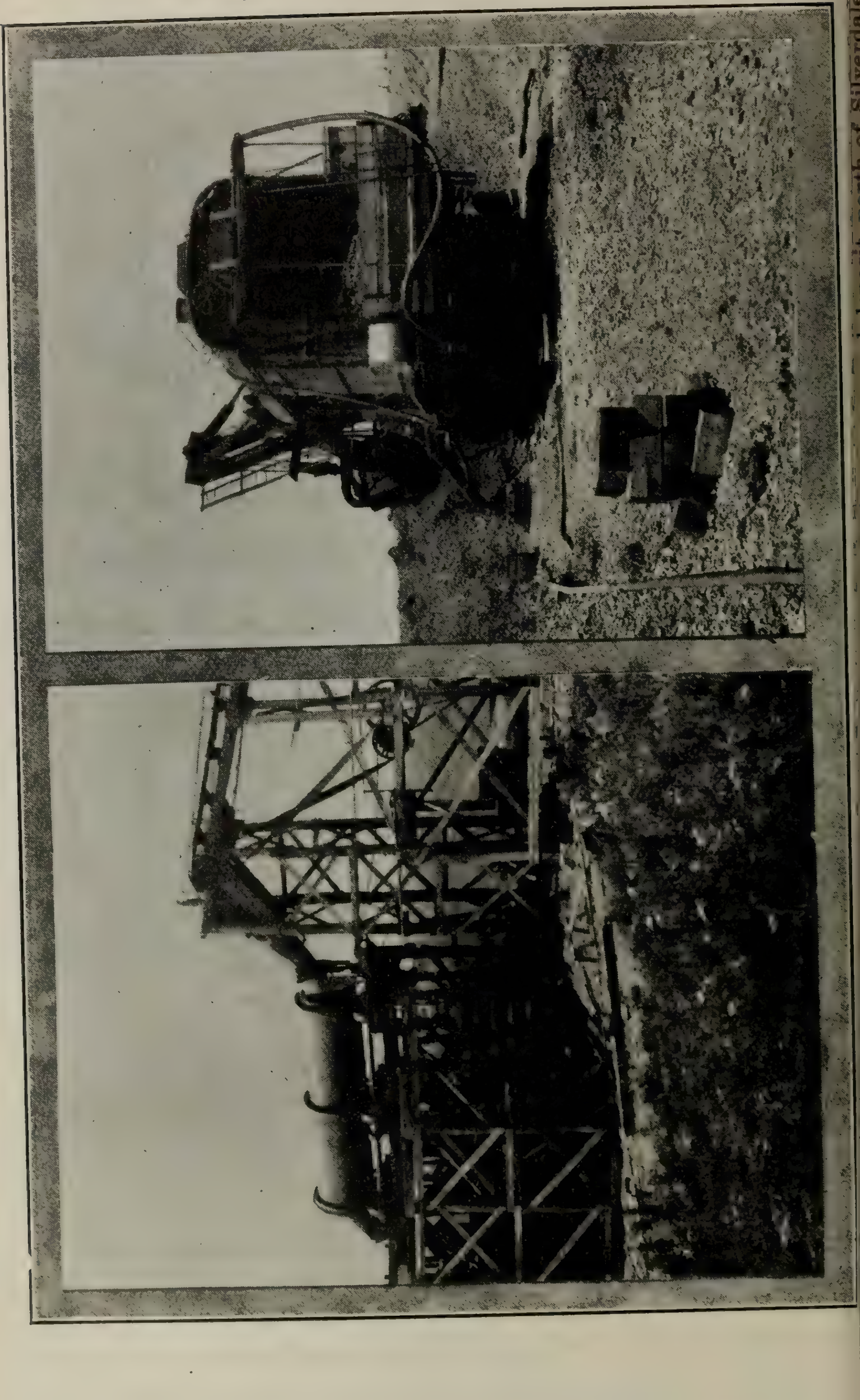
[1] For detailed discussion of the geology of Kansas, see Moore, Raymond C.; Oil and urces of Kansas; Geology of Kansas: Geol. Survey of Kansas, Bull. 6, pt. 2; 1920.



deposit, north of Silverdale.

vould enter the upper members of the Pennsylvanian sys- . The total thickness of the Pennsylvanian in this area is than 3,000 feet. As observed in the area of its outcrop in ern Kansas, the Pennsylvanian consists of a thick series lternating shale and limestone members with irregular beds ındstone and some beds of coal. From a quantitative stand-t, the shales are the most important of the Pennsylvanian s. The limestones are mainly light-colored, fossiliferous, grained rocks, many of the beds being also very cherty. ıed in order from top to bottom, the following formations ld be encountered in the well: Wabaunsee, Shawnee, glas, Lansing, Kansas City, Marmaton, and the Cherokee e. (See table, page 12.) Of these, the Wabaunsee is the one which appears at the surface in Cowley county.

embers belonging to the Wabaunsee formation, which has tal thickness of about 500 feet, outcrop in the southeastern of the county. The Wabaunsee consists of alternating stone and shale beds, the top member being the Eskridge e, which immediately underlies the Cottonwood limestone, the basal member the Burlingame limestone.

ıe succeeding lower members of the Pennsylvanian as they ld be encountered in a well are exposed in the same order ıe state is crossed from west to east from the eastern edge owley county. The Cherokee shale, the basal formation he Pennsylvanian, which should be encountered in a well Arkansas City at a depth of about 3,100 feet, is exposed ıe southeastern part of the state, covering most of Chero- and parts of Crawford, Labette and Bourbon counties. formation contains numerous sandstone beds which have en productive of oil and gas in areas where it is covered. ddition to the sands in the Cherokee, there are other very l sands found in higher formations of the Pennsylvanian. e of the more important of these are in shale members of Marmaton and Kansas City formations.

nmediately below the Cherokee shale, the Mississippian em, commonly spoken of as the "Mississippi lime," would ncountered. It was found at a depth of 3,270 feet in the land well south of Arkansas City. The Mississippi lime xposed at the surface in Kansas in a very small area in southeast part of Cherokee county, in the extreme south- part of the state. It consists chiefly of a crystalline limestone containing an unusual amount of hard chert, and co tains at least two sand "breaks" which have been producti of oil in southern Kansas and Oklahoma. The total thickne of the Mississippian in Kansas is estimated at about 350 400 feet.*

ECONOMIC GEOLOGY.

The natural resources of the Arkansas City district are and gas, clay, road materials, cement, building stone, sand a gravel, and water supply.

OIL AND GAS.

The Arkansas City district is centrally located with ref ence to a number of producing fields in both Kansas and Ok homa. (See figure 2.) The nearest fields are those in Kay a Osage counties, Oklahoma, and in Chautauqua, Elk and But counties, Kansas. There is some production in Cowley coun near Dexter and Maple City in the eastern part, and near W field in the central part of the county. (See plate III.) southern extension of the Fox-Bush pool of Butler cou extends a short distance into Cowley county on the north.

DEVELOPMENT.

The Dilworth field, a northern extension of the Blackw field, is located about 16 miles southwest of Arkansas City Oklahoma. The field was opened about 1912 and developm has continued intermittently up to the present time. The d production in the Blackwell field occurs at a depth of ab 3,300 feet. There are a number of producing sands at sh lower depths, a fairly good gas sand being found at ab 750 feet.

In the field located northwest of Newkirk, about 12 m south of Arkansas City, production has been encountered the Mississippi lime at a depth of about 3,400 feet. Ther also considerable production in the vicinity of Ponca C development work having been started in this field as e as 1904.

Chautauqua county, east of Cowley, has been an impor oil- and gas-producing area for a good many years. Pro tion in the Peru and Sedan fields is encountered in three sa —the Bartlesville, Peru and Red—found there at depth ut 1,200, 1,000 and 950 feet, respectively. Most of the oil lls in Chautauqua county are small producers, but are noted their long life, some of the wells having produced for as g as 12 or 15 years.

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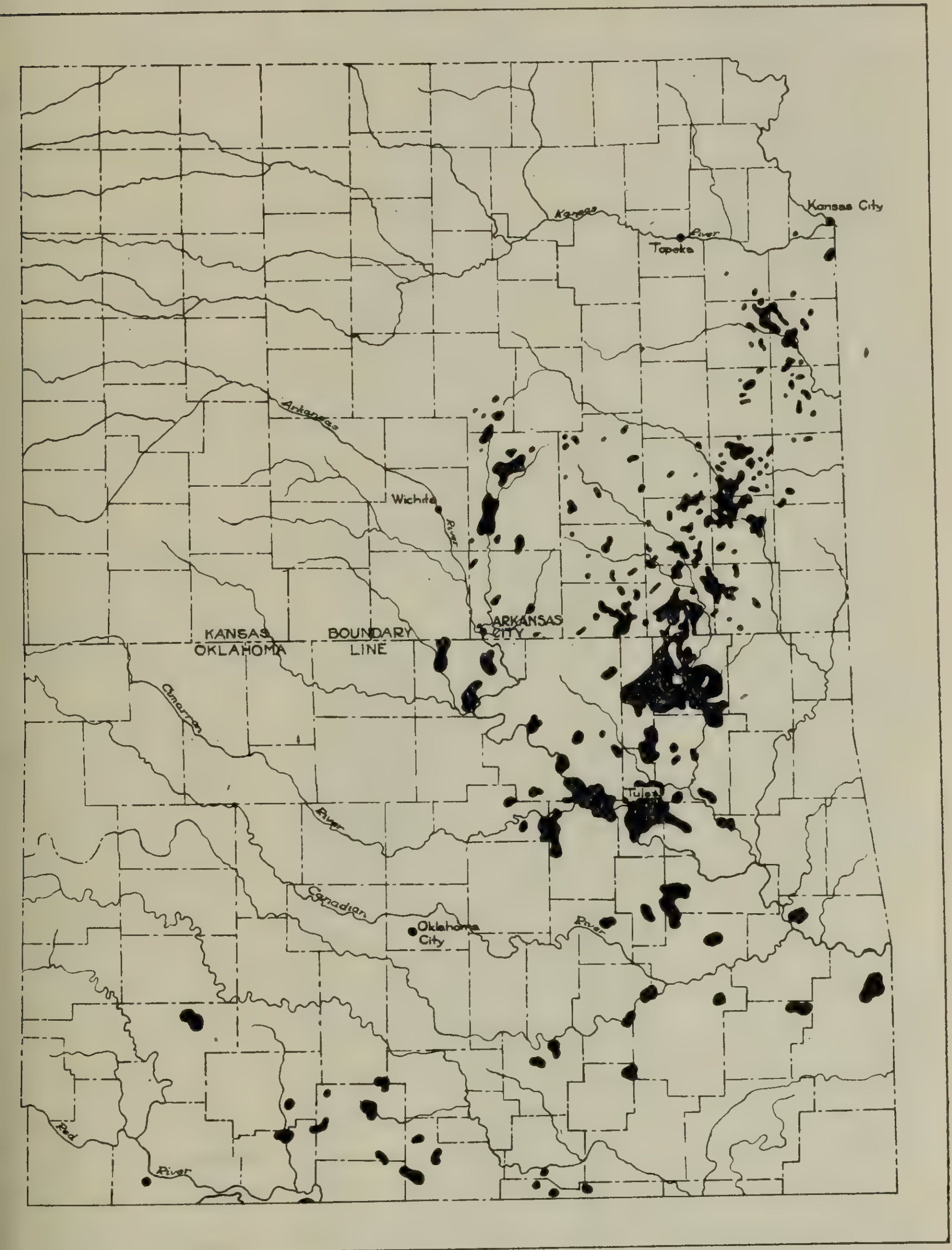
* It is possible, indeed probable, in some cases that these "breaks" are belo Mississippian.—State Geologist.



URE 2. Map showing location of Arkansas City with reference to the oil and gas fields of Kansas and Oklahoma.

The area of largest oil and gas production in Kansas is in tler county, just north of Cowley. Oil was first discovered commercial quantities near Augusta in 1914, although the unty had been producing gas for a number of years previous.

Most of the production in the Butler county fields is found in sands varying in depth from 1,700 to 2,700 feet. In the Fox-Bush field, in the southern part of the county, the main producing horizon is the Burgess sand, found at a depth of about 2,700 feet.

There are a number of small oil and gas fields in Cowley county. One area of considerable importance is located about seven miles southeast of Maple City, in sec. 17, T. 35 S., R. 7 E. Eleven wells have been drilled in the northeast quarter o this section, all of which are producing. The first well wa drilled in 1917. One well is producing gas at the rate of si million cubic feet per day from a sand at 1,400 feet. Anothe well was drilled to the Bartlesville sand at a depth of 2,66 feet and came in at about 200 barrels. The remaining well get their production from the Peru sand at a depth of abou 2,000 feet. The average initial daily production of the ten oi wells was about 100 barrels and the settled daily productio about 80 barrels per day.

An area in which considerable gas and oil is being produce is located southeast of Winfield. The production here is ob tained largely from sands from 1,400 to 1,700 feet in dept A very good gas sand is found in this area at a depth of fro 650 to 700 feet.

There are a few wells near Dexter, in eastern Cowley count some of which have been producing oil for several years. Pr duction in this area is found at a depth of about 2,200 fee from what is reported to be the Bartlesville sand.

There has been some development work within a radius of few miles of Arkansas City, some production, principally ga being encountered north of town as early as 1906. The wells, however, have been abandoned. There are several fair good gas wells about 4 miles southeast of town in sec. 4, T. S., R. 4 E. These wells are producing from a sand at a dep of about 1,925-1,950 feet, which probably belongs to the Ch nute or Cherryvale shale member of the Kansas City formati

A well of considerable importance in this district is t Marland well, located about 5½ miles southeast of Arkans City, in sec. 16, T. 29 N., R. 3 E., Kay county, Oklahoma. Th well was brought in at 700 barrels in May of 1920, and h settled to about 300 barrels. The production is obtained fr a sandy lime in the Mississippian at a depth of 3,635-3,6 feet. The Mississippi lime was encountered at 3,270 feet.

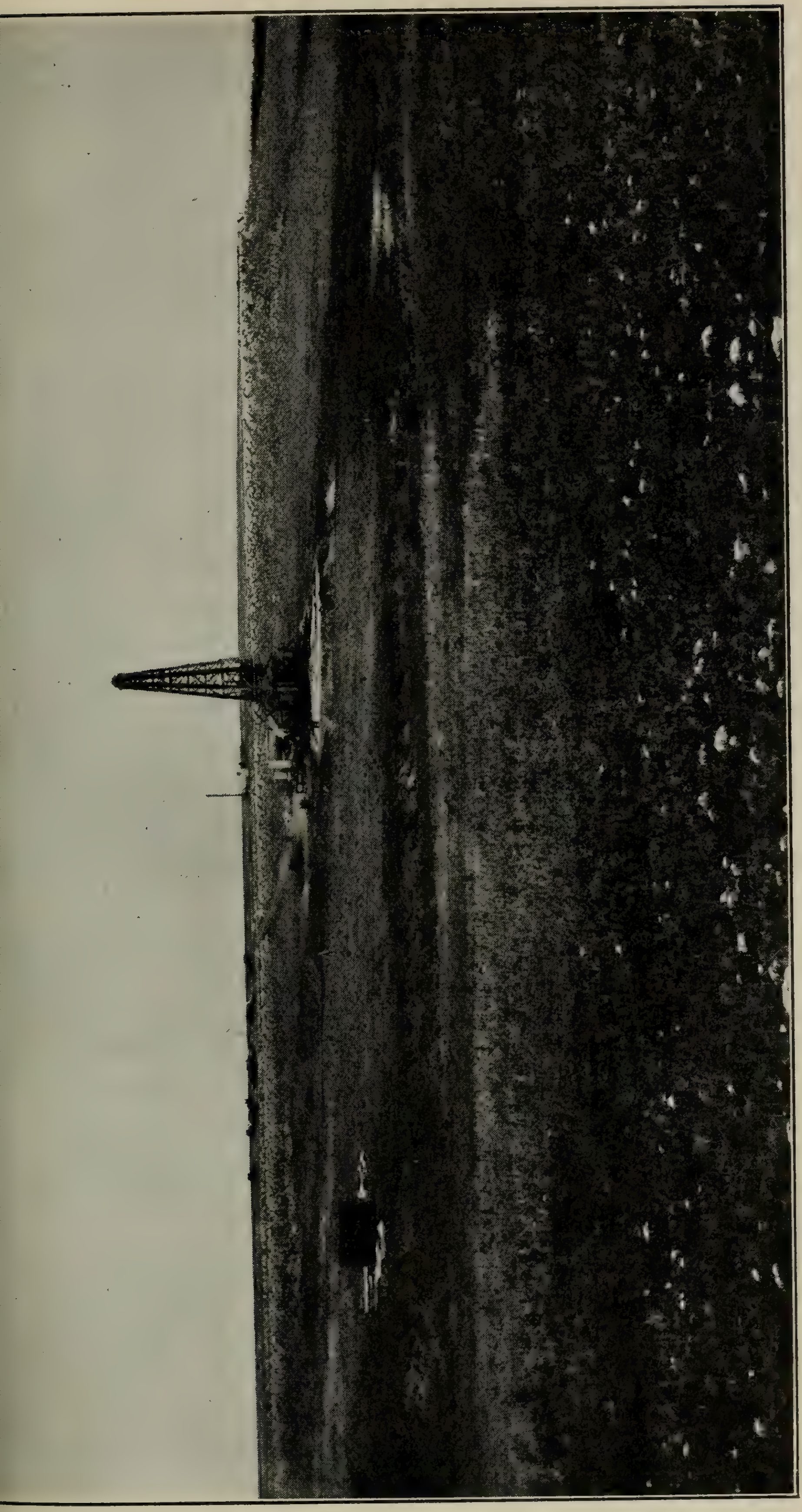


PLATE VII. Oil well in sec. 16, T. 29 N., R. 3 E., Kay county, Oklahoma, 5½ miles southeast of Arkansas City, showing also the outcrop of the Winfield limestone.

STRUCTURE.

In this area, as in other areas in the Midcontinent field geologic structures such as anticlines, domes and terraces are most favorable for the accumulation of oil and gas. It should be remembered, however, that the location of a well on favorable geologic structure does not guarantee the finding of oi or gas. Nevertheless, such a location does greatly diminish the risk attached to oil and gas prospecting. A number o conditions may exist beneath the surface, any one of which may cause a structure to be unproductive. There may be no porous stratum or "sand" capable of holding commercial deposits of oil or gas, and even if such a porous stratum i present it may be dry. The sand may be so tightly cemented that there is very little pore space, and consequently oil and gas cannot be present in large quantities. There is also possibility that the oil- and gas-bearing horizons do not conform t the surface formations, surface structure not being precisel reflected, therefore, in the lower strata. This latter conditio is of importance in the Arkansas City district, owing to th fact that a part of the production may be expected from th Mississippi limestone, and there is a known unconformity between the Mississippian and the overlying Pennsylvania formations. However, experience has shown that Mississippian production follows surface structure in general rathe closely.

A detailed structural examination was made in Township 34 and 35, South, Range 3 East, with the aid of a telescopi alidade and a plane table. The strata in this area have a general dip a little south of west, which amounts on the average t about 30 feet per mile. This normal dip is interrupted in number of places by small folds, which form domes, anticline or synclines. The arrangement of these folded areas is n regular, but in general they appear to trend slightly east north.

The geologic structure is shown on the map (plate VIII) b structure contours, which are imaginary lines connecting a points of equal elevation of the rock stratum. Since no sing limestone bed is found over the entire area, it was necessa to secure elevations on two different beds, the Winfield an Herington limestones. The interval between these beds w termined in a number of favorable localities and the elevans all reduced to a datum, the top of the Winfield limestone. e elevations shown on the contour lines indicate height ove sea level, and the contour interval is 5 feet.

The largest and most favorable structure in this area is ated in secs. 3, 4 and 9, T. 35 S., R. 4 E. This structure has maximum east dip of 23 feet in a distance of about threeurths of a mile. The north dip cannot be determined on acunt of lack of exposure in the broad valley of Arkansas river, t it is probable that the structure closes on the north. Seval gas wells are located in the valley in the northeast quarter section 4, which are thought to be on the north extension of is structure. A dry hole was drilled in the southwest corner section 4 to a depth of over 3,400 feet and was abandoned in e Mississippi lime. As seen from the accompanying strucre map, this well is located down on the west side of the ructure. A well was drilled in the southwest quarter of the rthwest quarter of section 3 to a total depth of 3,645 feet. is well encountered several gas sands, one near 1,400 and e at 1,951, corresponding to those found in the producing s wells in section 4, and also got an oil showing at 3,240-3,276 et. This test was located slightly east of the structure. See plate VIII.) Probably the best location for a deep test of is structure would be the center of the north line of the utheast quarter of section 4.

South of the structure just described, in the eastern part of ctions 9 and 16, is another structure, smaller than the first, ving an east dip of only a little over 10 feet in about onelf mile. The exact outline of this structure could not be termined on account of the lack of exposures in parts of secons 15 and 16, but it is very nearly as shown on the strucre map. Although this structure is not as large as that to e north, it is probably worth testing. It is interesting to ote that this structure, with the one in sections 4 and 9, are alost in line north and south with the structure on which the arland well is located, just a mile south of the state line, nd it seems very probable that there is some connection beween them.

There is a terrace-like structure in secs. 13 and 14, T. 34 S., . 4 E. The maximum east dip here is not over 5 feet, but the flat" covers an area of about a square mile. On the north of

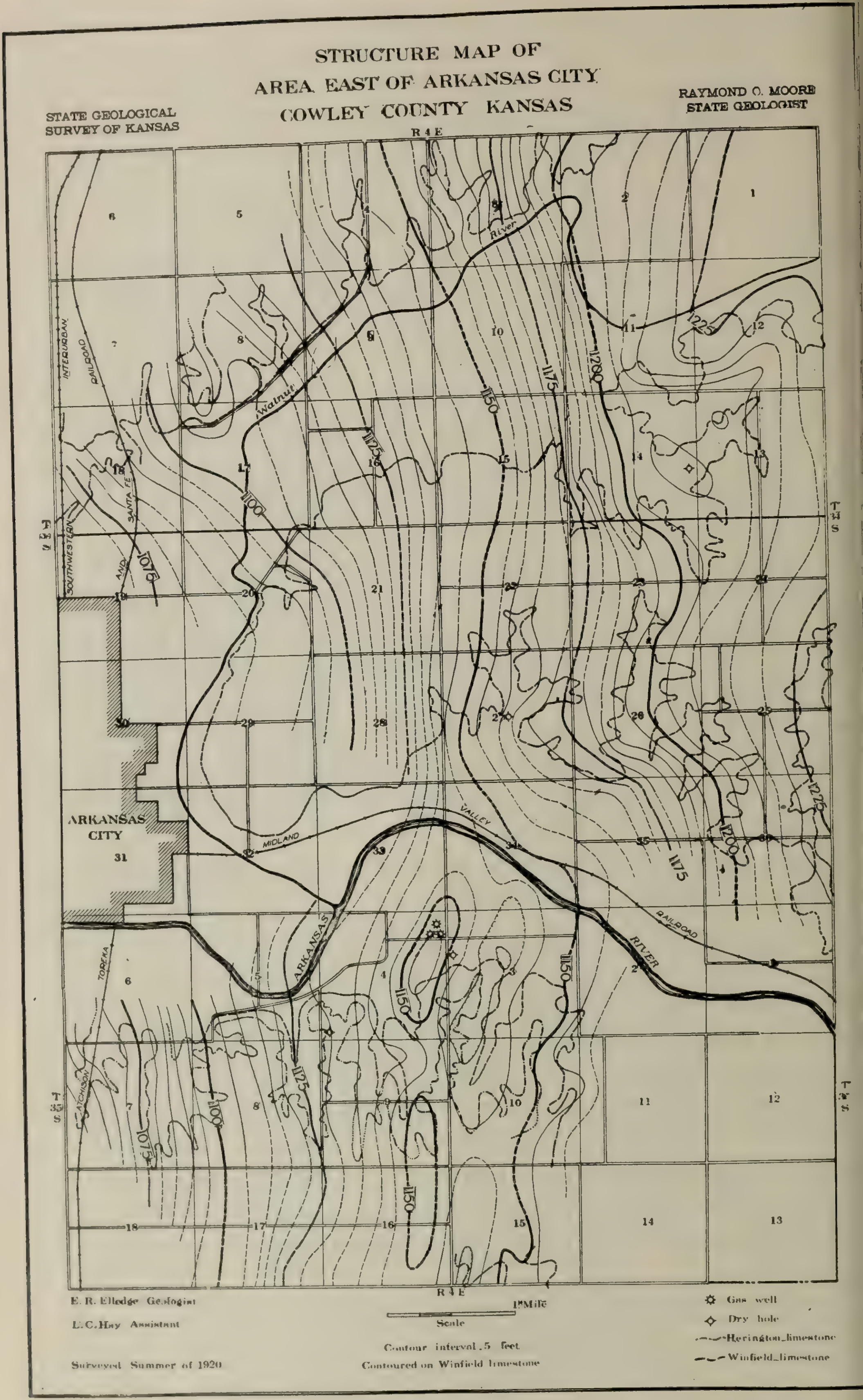

STRUCTURE MAP OF
AREA EAST OF ARKANSAS CITY
COWLEY COUNTY KANSAS
STATE GEOLOGICAL SURVEY OF KANSAS
RAYMOND C. MOORE STATE GEOLOGIST
R 4 E
T 34 S
T 35 S
ARKANSAS CITY
Walnut River
Arkansas River
INTERURBAN RAILROAD
SOUTHWESTERN
SANTA FE
MIDLAND VALLEY RAILROAD
ATCHISON TOPEKA AND SANTA FE
1075
1100
1125
1150
1175
1200
1225
E. R. Elledge Geologist
L. C. Hay Assistant
Surveyed Summer of 1920
1 Mile
Scale
Contour interval 5 feet
Contoured on Winfield limestone
Gas well
Dry hole
Herington limestone
Winfield limestone

PLATE VIII.

is terrace, in sections 11 and 12, is a "nose" with an east dip 9 feet and a south dip of 20 feet. A well was drilled in the ırtheast corner of the southeast quarter of section 14 on hat is probably as favorable a location as any on the terrace. ıis well was abandoned, but is reported to have been drilled a depth of less than 2,000 feet, so cannot be considered a thorough test of the structure. A location near the ırthwest corner of the southwest quarter of section 12 should ove whether or not the "nose" will prove productive.

There is also evidence of a small dome just north of Arınsas City, in sections 8 and 17. On account of the character the Herington limestone in this area, it was not possible to termine its exact size and shape. This is the area in which number of gas wells were drilled several years ago, but so far is known, no deep test has ever been made. The fact that e gas wells were found here makes a deep test very desirable.

It is reported that a favorable structure has been mapped st east of Silverdale and that a well is being drilled on it. ıis area was not mapped in detail, so its exact location and ze are not known.

Although several dry holes have been drilled in the area under discussion, it will be seen from the structure map that, ith one exception, they were not located on the most favorıle structures, and consequently do not condemn the area. he well drilled in sec. 14, T. 34 S., R. 4 E., was not drilled sufficient depth to be a thorough test of the structure on hich it is located. The fact that a number of good gas wells ıve been drilled on the structures discussed, and that the arland well, which has a settled production of 300 barrels, is cated just a mile from the southern edge of this area, and ıat there are several producing areas located within 25 miles Arkansas City, make desirable, in the writer's opinion, the sting of these structures. In order to make these tests thorıgh, the wells should be drilled at least to the second "break" the Mississippian. Since recent subsurface investigations[2] Kansas and Oklahoma indicate that much important proıction is coming from rocks even older and lower than the lississippian, thorough testing of the Arkansas City strucıres should require drilling deeply into or through these prelississippian rocks.

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2. Aurin, F., Clark, G. C., and Trager, E.; Pre-Pennsylvanian stratigraphy of the idcontinent region: Bull. Am. Assn. Petroleum Geol., vol. 5, No. 2; March, April, 1921.

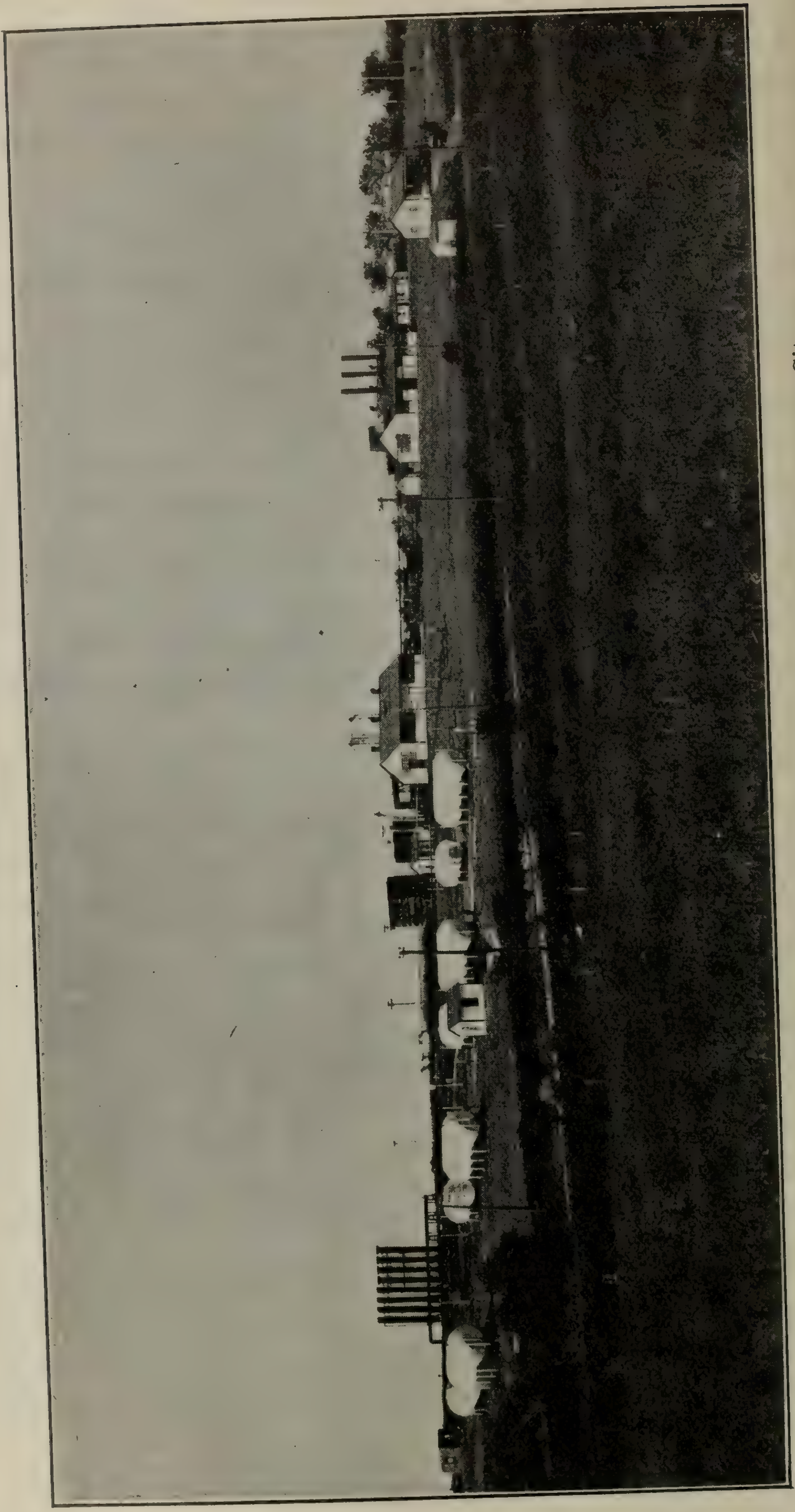


PLATE IX. The Empire natural-gas gasoline refinery at Arkansas City.

REFINERIES.

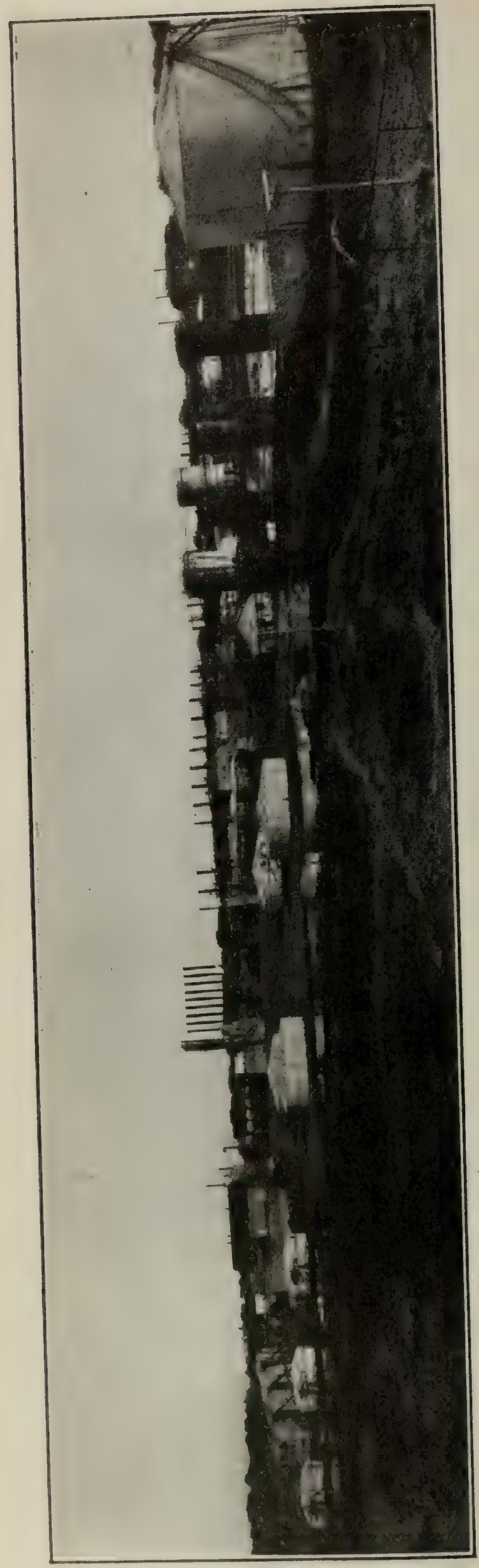
'he four refineries located in Arkansas City are centrally ated with reference to production in both Kansas and Okla- na. They also have the advantage of adequate transpor- ion facilities, the town being connected by railroad lines h the fields of Butler, Chautauqua and other counties in nsas, and with those in Kay and Osage counties in Okla- na. The refineries in operation at the present time include ee crude-oil refineries and one natural-gas gasoline plant. ese are the Millikan refinery, now being operated by the l-Co. Oil Company, capacity, 6,000 barrels of crude oil ly; the Kanotex refinery, capacity, 3,500 barrels of crude daily; the National Oil Company refinery, capacity, 40,- barrels of crude oil monthly; and the natural-gas gaso- plant of the Empire Gas and Fuel Company, capacity, 60,- ,000 cubic feet of gas per day, yielding 8,000 gallons of oline.

CLAY.

n investigation of the clay and shale resources of the ansas City area was made in order to locate any deposits ich might be of value in the manufacture of clay products. nples of the clay deposits which might be suitable were en under the direction of Mr. Paul Teetor, ceramic engi- r of the Geological Survey, and were sent to the ceramic oratory for testing. The final results of these tests are dis- sed in an accompanying report by Mr. Teetor.

'here is an inexhaustible supply of clay shales in the vicin- of Arkansas City, but their possible utilization in a com- rcial way depends, of course, on a variety of factors: first all, the chemical and physical properties of the clay; next, locally available quantity, accessibility, amount of over- rden, etc. In the field examination, samples were taken m localities where these geographic conditions were favor- e.

n order to make the field investigation as complete as sible, samples were taken from all the shale members which ear at the surface. These members are the Pearl shale, Enterprise shale, and the Doyle shale. On account of fact that these individual geologic horizons are similar r the entire area, their physical and chemical properties



l vary only slightly in a distance of two or three miles, and number of samples taken is sufficient to determine the ue of all the shales appearing in the area.

ROAD MATERIALS.

)wing to the commercial opportunities and advantages of od roads to any community, the subject of road materials is vital interest to all residents of the Arkansas City district. e expense of road improvement is dependable to a large ext on the character, abundance and accessibility of local terials. If suitable materials are readily available in the inity of a proposed highway, the cost of construction is reced to a minimum, but if it is necessary to transport the terials a great distance the cost is very materially increased. The materials which are found in this district which are ailable for road construction are limestone, sand and gravel. studying these materials, samples of all which it was ought might prove satisfactory were collected and sent to e State Road Materials Testing Laboratory at Manhattan, here tests were made to determine their physical properties. These tests as made at the laboratory determine the specific avity, per cent of wear, French coefficient of wear, hardness, ughness and cementation of the material submitted. In der to meet the specifications for use in a concrete rod, stone r use in the base course should have a French coefficient of ear of not less than 5 and toughness not less than 4; and for e in the surface course, French coefficient of 8 and toughss 6.

SAMPLES.

The report on a sample of limestone collected from the W¼ of sec. 10, T. 35 S., R. 4 E., shows that this material as a French coefficient of wear of 5 and would probably give tisfactory results if used in the base course of a concrete macadam road. This material was taken from the lower ed of the Herington limestone member. The thickness of e bed is about 2½ feet.

A sample of limestone was taken at the quarry in sec. 1, . 35 S., R. 4 E. Tests on this material show that the French oefficient is slightly below specifications, being only 4.8. This as sampled from the Fort Riley limestone member, which about 40 feet thick. The stone varies in its physical properties, but the sample was thought to be representative of the quarry. The better grade of this material would be satisfactory for use in the base course.

A sample of the Herington limestone was collected in NW¼, sec. 7, T. 35 S., R. 4 E. This stone has a French coefficient of 4.5, slightly below specifications, but would probably give satisfaction if used in the base course. The thickness of the ledge exposed in this locality is about 5 feet.

Tests on a sample of the Winfield limestone taken in NW¼, sec. 36, T. 34 S., R. 4 E., indicate that this stone is too soft for use in road construction.

A sample was taken of the sand which is being pumped from Arkansas river east of Arkansas City by the Arkansas City Sand Company. The report from the laboratory states that this is a good, clean sand and would be satisfactory for use as fine aggregate in concrete work. It is a medium coarse sand, and the supply is practically unlimited, as a good grade of sand can probably be found at a number of places along the river.

A sample of washed gravel from the pit three miles north of Silverdale was sent to the laboratory, and their report states that this is a very hard and well-graded material which will give excellent results as road material. This gravel as taken from the pit is mixed with a red clay, and has been used locally for road building just as taken out, with good results. After a little use, the gravel with the clay binder forms a hard, comparatively impervious road bed. With a little care this type of road will give very satisfactory results.

CEMENT.

There are not at the present time any cement plants in operation in the vicinity of Arkansas City, but it is reported that a small amount of cement was manufactured several years ago from material obtained from the quarry in the Fort Riley limestone in sec. 1, T. 35 S., R. 4 E. The project was abandoned, however, before the cement had been manufactured in commercial quantities. No samples of the materials which are necessary for the production of cement—namely, limestone and shale—were taken, as the Survey is not at the present time equipped to make the necessary tests. It is probable, however, that satisfactory materials are present in this area.

BUILDING STONE.

e most satisfactory stone for building purposes found in rkansas City district is the Fort Riley limestone. This e both to the character of the stone and the thickness of edge. The Fort Riley is quarried for building stone at uarry two miles north of Silverdale. The Winfield lime- is too soft and porous for use as building stone. The ngton is hard enough in some localities, but in others is too soft. The lower bed of the Herington has been locally for building stone from a quarry in sec. 10, T. 35 . 4 E.

WATER SUPPLY.

e city of Arkansas City has an abundant supply of good r obtained from four wells located in the Arkansas river y, the source of supply being the underflow of the river. e wells are about 60 feet deep, and combined have a pump- apacity of four million gallons per day. The water is prac- ly inexhaustible, as the valley here is nearly five miles and the alluvial material is from 30 to 100 feet thick, thus ding an enormous reservoir. A plentiful supply of water be obtained at comparatively shallow depths any place e valleys of the Arkansas and Walnut rivers in this area. from the Walnut is, however, so highly mineralized on unt of salt water and other waste products from the oil s to the north that it cannot be used for domestic purposes. e higher areas back from the rivers the water is obtained shallow wells drilled in the sedimentary rocks and from erous springs. Most of the area has an adequate supply round waters at comparatively shallow depths.

hroughout the area in which the Winfield limestone is ex- d there are numerous springs located near the top of this stone which furnish a good supply of water. One such ng is located about two miles southeast of Arkansas City, he southwest corner of sec. 5, T. 35 S., R. 4 E. Another bout two miles northeast of town, in the NE¼, sec. 20, 4 S., R. 4 E. So far as was learned, these springs are not rmittent, and furnish a large amount of water during the re year.

ight miles northwest of Arkansas City, at the little town Geuda Springs, is situated a rather remarkable group of

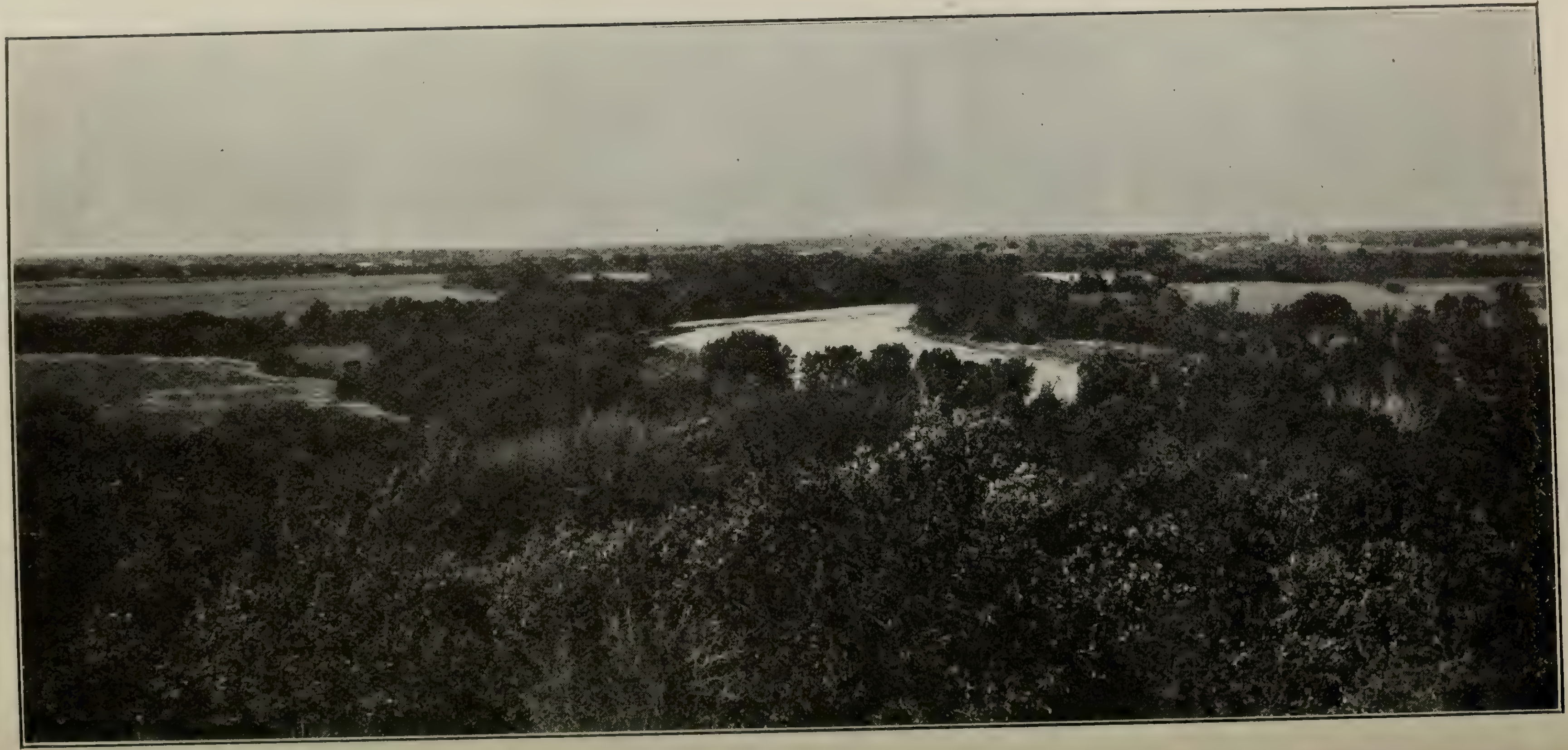


PLATE XI. View of the flood plain of Arkansas river, looking west towa rd Arkansas City.

springs. The water which flows from these springs is mineralized and is considered beneficial for medicinal es. As a result of the medicinal properties of this Geuda Springs is more or less of a health resort, and hotel, a bathhouse and hospital for the accommodation tors.

Clay and Shale Resources in the Vicinity o Arkansas City, Kan.

By Paul Teetor.

INTRODUCTION.

An investigation of the clays and shales was made in co- nection with the work which was conducted under the coöper- tive arrangement made between the State Geological Surv of Kansas and the Chamber of Commerce of Arkansas Ci Kan.

The field work—that is, the locating and sampling of t clay and shale deposits—was done by the writer, assisted Mr. E. R. Elledge and Mr. Lawrence Hay. The entire a around Arkansas City was thoroughly prospected and samp were taken of every deposit which had any possibility of ing of commercial value.

PROPERTIES AND TESTING OF CLAYS.

The clays and shales occurring in the Arkansas City reg belong to the class which is utilized in the manufacture structural products. These products are practically all m by either the stiff-mud process or the dry-press process shaping. In the former case the clays or shales are crus and mixed with sufficient water to form a plastic mass wh can be forced through a die to produce a column of pla clay of the proper cross section. The column is then sliced i units of proper thickness. In the dry-press process the cl or shales are crushed and mixed with from 6 to 10 per cen water, and the moist, finely divided material is fed into a m die box and sufficient pressure exerted upon the top and bot of the die to compress the clay into a mass of sufficient stren to withstand the ordinary handling in the process of manu ture. For this second type of clay the following tests ar importance in determining the commercial value of the posits.

The working properties of the plastic mass, after the pr amount of water has been added to produce best wor

perties, are of prime importance. If the clay is not plastic
ugh the clay column will not hold together as it issues from
die; if too plastic it will develop laminations while being
ped, and is also very likely to crack while drying.

he percentage of drying shrinkage is also of importance,
ause a clay with a high drying shrinkage is very apt to
k during drying.

he properties of the clay after it has been burned at differ-
temperatures are of prime importance, the three most im-
ant properties being color, burning shrinkage, and porosity.
m the burning shrinkage can be estimated the warping and
king which can be expected during burning. The porosity
s an estimate of the strength and also of the range of
perature in which the clay can be properly matured in the
. By porosity is meant the pore space present in the
ed specimen, and this is determined by dividing the weight
ater absorbed by the specimen while submerged in water
er a vacuum, by the volume of the piece.

is also a well-known fact that the presence of limestone
icles, coarser than 30-mesh, in a clay render it useless for
manufacture of structural clay products, owing to the fact
during the firing of the clay the limestone is converted to
. Upon exposure to the atmosphere the lime absorbs water
is converted into lime hydrate, with an increase in volume
a resulting pressure on the surrounding clay particles suffi-
t to cause a rupture known as a "popped brick."

ARKANSAS CITY CLAYS.

here are a number of shales in the Arkansas City area.
e are soft shales containing limestone concretions and are
to cut with a pick and shovel, while others are very hard
might be termed shaly limestone. In each case a ten-
d sample was secured by cutting away the weathered face
he outcrop and taking the sample so as to represent the
re depth of the exposed deposit. These samples were sent
he ceramic laboratory of the State Geological Survey for
iled testing to determine the commercial value of the
ous deposits. There were in all eight deposits of shale
h appeared worthy of tests. A description of these de-
ts and the results of the tests follow.

PEARL SHALE.

Sample No. 505 represents a typical deposit of the Pearl shale located in the southeast corner of sec. 21, T. 34 S., R. 3 E., three miles from Arkansas City and three-fourths mile from the railroad. It has a thickness of 10 to 12 feet, is 500 feet long (estimated), and is probably 300 to 400 feet wide. There is an overburden of 15 to 20 feet, which contains limestone. This overburden is so thick compared to the thickness of the deposit itself, that it could be removed only at a cost prohibitive, under normal conditions, to the manufacture of structural material such as brick and tile. It is therefore probable that this deposit is of no commercial value.

This clay has poor working properties as regards its fitness for working by the stiff-mud process, even when ground to pass the 10-mesh sieve, although when passed through a 20-mesh sieve its working properties are slightly better. It should work best by the dry-press method of shaping. Its water of plasticity is 19.8 per cent and its drying shrinkage 4.83 per cent. The clay, after being ground and mixed with water to produce the best working properties, was molded by hand into briquettes. These were dried and the drying shrinkage obtained. They were then placed in a kiln for the purpose of determining the properties of the clay at higher temperatures. Pieces were drawn from the kiln at temperatures of Seger cones listed below, the approximate equivalents in the Fahrenheit scale as reported by the manufacturers being also given

Cone 010	174½° F.
Cone 07	1,850° F.
Cone 05	1,922° F.
Cone 02	2,030° F.
Cone 1	2,102° F.
Cone 3	2,174° F.
Cone 5	2,246° F.
Cone 7	2,318° F.

The final specimens were examined for burning shrinkag porosity, color, and hardness. These data are given in table

Sample No. 505, when ground to pass a 10-mesh sieve coarser, produces a brick of dark-brown color and one th disintegrates rapidly when exposed to the weather. This due to the formation of lime hydrate from free lime particl which are present. When ground to pass a 20-mesh sieve produces a sound brick at cone 4, with a beautiful brown colo

Table No. 1.

	Temperature.							
	Cone 010.	Cone 07.	Cone 05.	Cone 02.	Cone 1.	Cone 3.	Cone 5.	Cone 7.
Burning shrinkage, per cent....	....	0.69	1.60	1.60	2.12	3.19	2.29	28.96
Porosity, per cent....	....	45.94	43.90	43.98	39.50	38.70	20.33	68.02
Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.
Color........	Grey brown.	Light brown.	Light brown.	Light brown.	Brown.	Brown.	Brown.	Brown.
Burning shrinkage, per cent....	-3.33	-3.33	-3.33	-3.33	-4.03	-2.67	0.89	7.64
Porosity, per cent....	56.50	55.30	55.30	55.42	54.82	54.17	44.97	29.45
Hardness.....	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.
Color........	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Cream.	Cream.	Cream.
Burning shrinkage, per cent....	-2.27	-1.34	-2.24	-2.02	....	3.18	1.80	-2.02
Porosity, per cent....	63.75	61.31	62.82	62.78	62.91	63.14	61.82	62.56
Hardness.....	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.
Color........	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.
Burning shrinkage, per cent....	1.87	3.26	3.96	2.13	2.82	6.66	Melted.	Melted.
Porosity, per cent....	25.61	25.31	21.30	22.06	15.43	4.05	....	....
Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....	....
Color........	Light red.	Light red.	Red.	Red.	Red.	Red.	....	....
Burning shrinkage, per cent....	2.92	5.46	6.12	6.35	6.13	6.36	Melted.	Melted.
Porosity, per cent....	23.72	22.13	19.58	16.81	13.01	3.62	....	....
Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....	....
Color........	Brown.	Brown.	Brown.	Brown.	Brown.	Brown.	....	....

Table No. 1—Concluded.

Sample No.		Temperature.							
		Cone 010.	Cone 07.	Cone 05.	Cone 02.	Cone 1.	Cone 3.	Cone 5.	Cone 7.
510	Burning shrinkage, per cent....	-1.17	....	0.70	1.88	0.93	1.40	4.94	....
	Porosity, per cent....	43.11	....	45.05	44.51	43.77	43.48	33.49	....
	Hardness.....	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	....
	Color........	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Cream.	Cream.	....
511	Burning shrinkage, per cent....	0.71	0.71	....	2.13	1.90	0.69	6.99	....
	Porosity, per cent....	44.58	45.27	46.60	36.10	25.27	31.70	2.11	....
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....
	Color........	Dark gray.	Dark gray.	Greenish gray.	Greenish gray.	Greenish gray.	Green-yellow.	Mustard.	....
512	Burning shrinkage, per cent....	0.95	1.41	1.63	2.34	5.15	6.55	5.15	....
	Porosity, per cent....	26.16	....	26.39	25.57	13.93	8.35	1.85	....
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....
	Color........	Light red.	Light red.	Red.	Red.	Red.	Dark red.	Dark red.	

To obtain this degree of fineness in commercial manufacture however, would require the installation of special grindin equipment. The maturing range of the clay is also ver short. Therefore, while making a satisfactory brick unde certain conditions, this clay is not a promising one from commercial standpoint.

ENTERPRISE SHALE.

Sample No. 506 represents a deposit of clay which is a par of the Enterprise member, located in the northeast corner o the NE¼ NW¼, sec. 7, T. 34 S., R. 4 E. This deposit is feet thick, 300 feet long (estimated), and 150 feet wide. I carries a 6-inch ledge of limestone in the center and has 6 t 8 feet of overburden. The exposure from which the sampl was taken is three miles from Arkansas City, one-fourth mil from a railroad, and one-fourth mile from the interurban rail

This clay was tested by the same method as described ·o. 505. It has very poor working properties in the plastic and could not be worked by stiff-mud methods. Its r of plasticity is 20.61 per cent; drying shrinkage is 2.71 ent. The properties of the fired specimens are given in 1. It is interesting to note that this clay, upon being expands instead of shrinking. It contains a high per-ge of limestone in a fine state of subdivision. The poor ing properties and the softness of the fired material ren-his clay unfit for the manufacture of structural clay prod-

mple No. 507 represents another part of the Enterprise located in the northeast corner of the NW¼, sec. 35, S., R. 4 E., 8½ miles from Arkansas City, 4 miles from ailroad, and 4 miles from the interurban. It is so similar). 506 that the same statements hold true for both clays. available clay at this locality is 40 feet thick, 1,000 feet and covered with a 3-foot ledge of limestone.

mple No. 509 was collected from the Enterprise shale lo-in the SW¼ NE¼, sec. 18, T. 34 S., R. 4 E. The work-deposit here is 18 feet thick, 500 feet wide, and 500 feet (estimated), and is covered with 15 feet of limestone. ı ground and mixed with water to produce maximum ing qualities it is found that 18.17 per cent water is re-d. The working properties are very poor and it would e possible to work the clay by modern stiff-mud methods. rying shrinkage is 3.83 per cent. The properties of the men when fired at different temperatures are given in 1. This shale contains a large amount of coarse lime-which renders it practically useless, because when ed at a low temperature it will disintegrate upon ex-re to the weather, and at higher temperatures it softens f shape.

mple No. 510 represents a deposit of the same shale out-ɔing in the NE¼ SW¼, sec. 18, T. 34 S., R. 4 E., on the ıwest side of the same hill in which sample No. 509 oc-The water of plasticity of this clay is 20.88 per cent. drying shrinkage is 6.55 per cent. This clay, unlike sam-No. 509, has very good working properties in the plastic ition. When fired in a kiln, however, it is found that naterial does not develop sufficient strength and hardness to be of value for the manufacture of brick and tile. It als contains limestone particles of sufficient size to cause disintegration of the bricks after they come from the kiln. The properties of the fired specimen are given in table 1.

Sample No. 511 was also collected from a deposit of the Er

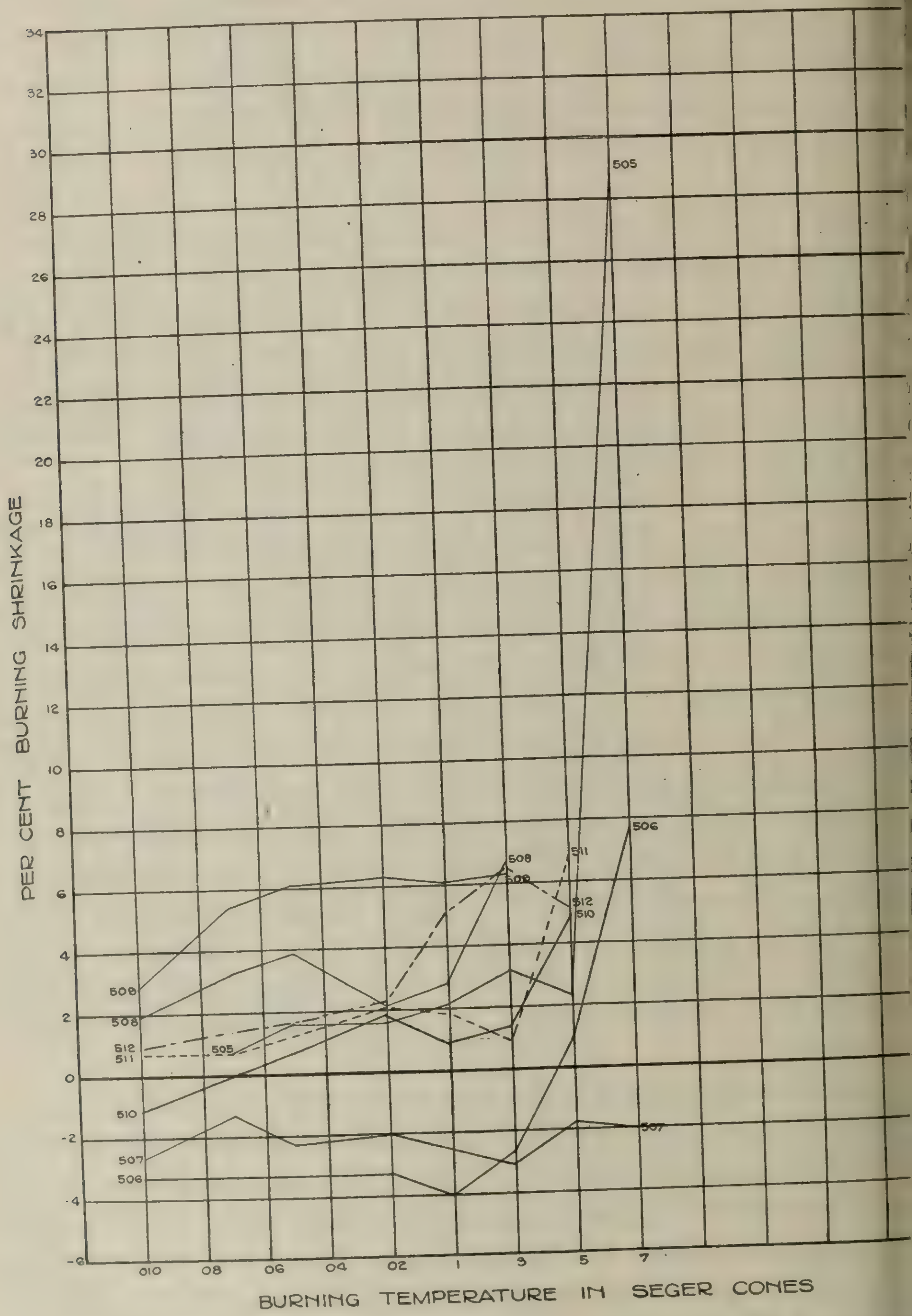


PLATE XII. Burning shrinkage-temperature curves of Arkansas City clays.

ise shale in the northwest corner of the SW¼, sec. 3, T. , R. 4 E., 4½ miles from Arkansas City, 3 miles from the ɔad, and 4½ miles from the interurban railroad. The able deposit is at least 6 feet thick, 300 feet wide and 500 long (estimated), and with little or no overburden. It red 20.19 per cent water to develop best plasticity. It ery good working properties and can be easily shaped in stiff-mud condition. The drying shrinkage is 9.33 per The properties of the burned test pieces are given in 1. When fired at a temperature of cone 05 or lower, the s disintegrate owing to the coarse particles of limestone ɛnt. At cone 4 it has softened sufficiently to cause the s to stick together. This gives it a narrow maturing e. Therefore, it is not a good clay from a commercial point. Further tests might develop the fact that it could ilized for the manufacture of a yellowish buff-colored face

DOYLE SHALE.

mple No. 508 represents a deposit of the Doyle shale lo- d in the southeast corner of the SW¼, sec. 35, T. 33 S., R. , which is 7½ miles from the interurban railroad. It is a ure of red, green and yellow clays located on top of lime- e, and is 8 to 10 feet thick, 300 feet wide, and 500 feet long imated). The overburden consists of limestone and varies hickness from a few inches to 15 feet. This clay when ınd and properly mixed with water has very good working erties and could be worked by any of the methods in mon use for the manufacture of such products as brick, etc. Its water of plasticity, or the amount of water neces- to add to produce the best working properties, is 22.25 cent of its dry weight. The drying shrinkage is 7.06 per . The clay also has very good burning properties as re- ds shrinkage, porosity, color and hardness. It needs to be ned at a temperature not below that of cone 05, but cone 1 ld be a more suitable temperature, as it would produce a duct of better color and strength. Data for the burned clay given in table I. The briquettes made from this clay, after ıg fired to the best maturing temperatures, slowly disinte- te, due to the presence of lime particles. This deposit is, refore, of no commercial value.

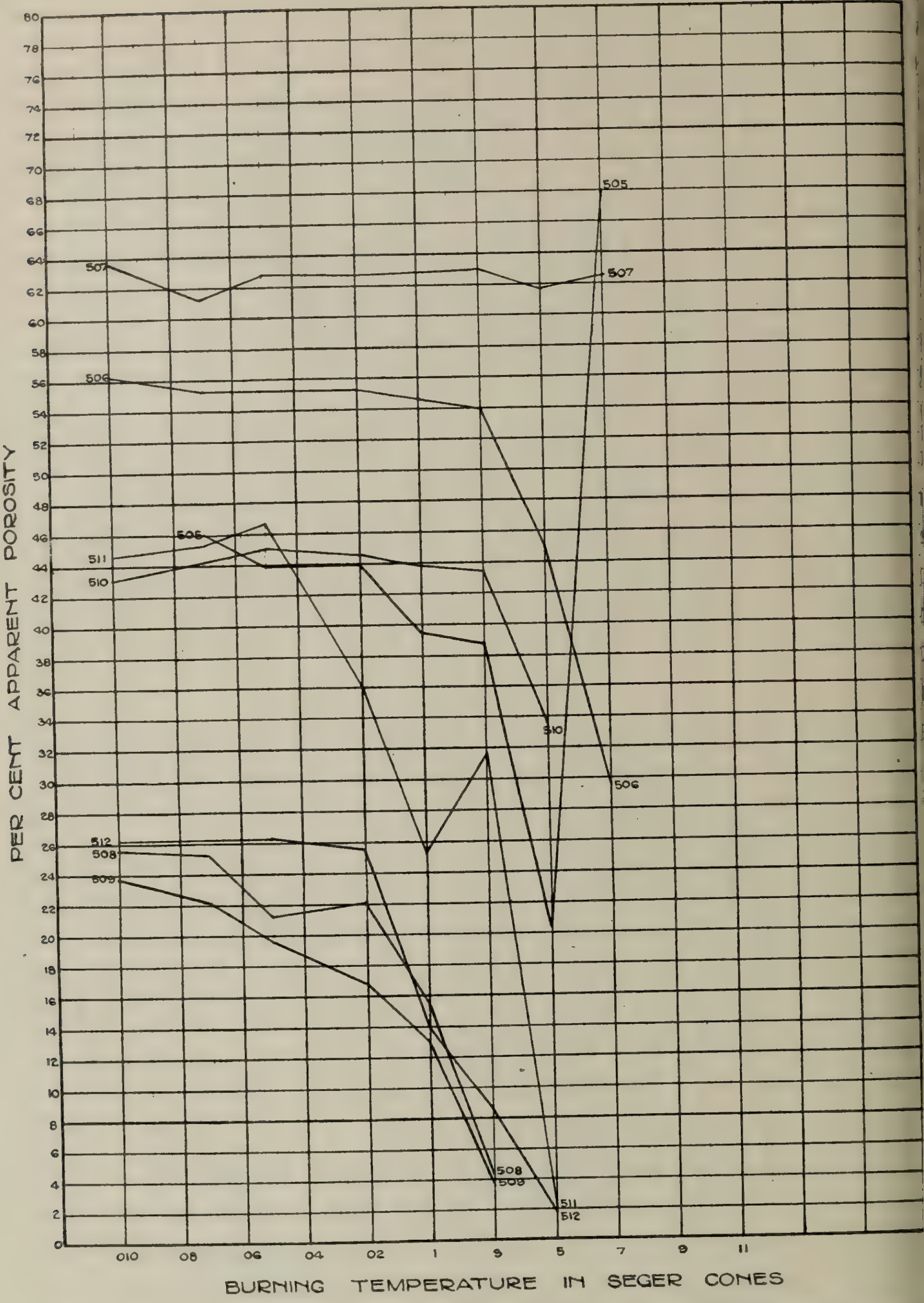


PLATE XIII. Porosity-temperature curves of Arkansas City clays.

Sample No. 512 was also taken from a deposit of the Doy shale located in the northwest corner of the NW¼, sec. 1 R. 34 S., R. 4 E. It is one mile from the interurban railroa and about one-half mile from the Santa Fe. The exposed po tion is 5 feet thick and 150 feet wide. The overburden is fro 4 to 10 feet thick. The water of plasticity is 21.38 per cer

ing shrinkage is 6.55 per cent. When ground and mixed
ı water it has good working properties and good plas-
y, and can be shaped by the stiff-mud process now in com-
ı use. The properties of the burned specimens are given
able 1. When fired, the clay disintegrates when exposed
he atmosphere. At cone 5 it has softened sufficiently to
se slight sticking. It develops a good red color, with an
sional yellow spot due to lime particles. This clay could
tilized for the manufacture of brick and tile in so far as
color of the clay is concerned, but on account of the lime
ch is contained, is of little commercial value.

is of interest to note that the samples collected from the
le shale member, Nos. 508 and 512, are by far the best
s tested and practically the only ones possessing proper-
approaching commercial value. It would appear that the
t promising field for future prospecting would be for out-
s of the Doyle shale member. The burning shrinkage-
perature relations of these clays are graphically shown in
e XII. The porosity-temperature relations are shown in
e XIII. These curves are self-explanatory.

Dup 38

STATE GEOLOGICAL SURVEY *of* KANSAS
RAYMOND C. MOORE, *State Geologist*

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BULLETIN 8

The Economic Geology of the Arkansas City District

By EMMETT R. ELLEDGE

Clay and Shale Resources in the Vicinity of Arkansas City, Kansas

By PAUL TEETOR

In coöperation with the Chamber of Commerce,
Arkansas City, Kan.

Printed by authority of the State of Kansas

PRINTED BY KANSAS STATE PRINTING PLANT
B. P. WALKER, STATE PRINTER
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CONTENTS.

onomic Geology of the Arkansas City District:

By Emmett R. Elledge.

PAGE
Introduction 5
  Location 5
  Acknowledgments 7
  The environment of Arkansas City 7
  Development of the Arkansas City district 9
Geology 11
  Rocks exposed in the Arkansas City district 13
    Chase formation 14
    Marion formation 16
    Wellington formation 18
    Quaternary deposits 19
  Concealed rocks in the Arkansas City district 19
Economic geology 22
  Oil and gas 22
    Development 22
    Structure 26
    Refineries 31
  Clay 31
  Road materials 33
    Samples 33
  Cement 34
  Building stone 35
  Water supply 35

ay and Shale Resources in the Vicinity of Arkansas City:

By Paul Teetor.

Introduction 38
  Properties and testing of clays 38
Arkansas City clays 39
  Pearl shale 40
  Enterprise shale 42
  Doyle shale 45

ILLUSTRATIONS.

PLATE.

I. Summit street, Arkansas City, looking north.

II. Views in Arkansas City business section.

III. Geological and production map of Cowley county, Kansas.

IV. *Above:* Outcrop of Herington limestone north of Arkansas Cit *Below:* Exposure of Fort Riley limestone in quarry in se 1, T. 35 S., R. 4 E.

V. *Left:* Quarry in Fort Riley limestone north of Silverdale. *Righ* Exposure of Winfield limestone at Horseshoe Hill.

VI. *Left:* Gravel washer north of Silverdale. *Right:* Pleistoce gravel deposit north of Silverdale.

VII. Oil well in sec. 16, T. 29 N., R. 3 E., Kay county, Oklahoma, 5 miles southeast of Arkansas City, showing also the outcrop the Winfield limestone.

VIII. Structure map of area east of Arkansas City, Cowley coun Kansas.

IX. The Empire natural-gas gasoline refinery at Arkansas City.

X. *Above:* Milliken oil refinery. *Below:* Kanotex oil refinery.

XI. View of the flood plain of Arkansas river, looking west tow Arkansas City.

XII. Burning shrinkage-temperature curves of Arkansas City cla

XIII. Porosity-temperature curves of Arkansas City clays.

FIGURE.

1. Location map of the Arkansas City district.

2. Map showing location of Arkansas City with reference to the oil gas fields of Kansas and Oklahoma.

he Economic Geology of the Arkansas City District.

By Emmett L. Elledge.

INTRODUCTION.

“The biggest town of its size in the United States,” re-
arked my friend in the Pullman smoking compartment as
e rolled swiftly past the green fields of a part of central
ansas, “is Arkansas City, down near the south line of the
ate. When you talk about wide-awake business ‘go,’ pro-
essiveness, and all the other things that make a town worth
hile—clean, paved streets, fine schools and churches and nice
mes—you may put our city right alongside of any of them in
e good old U. S. A., and I’ve been a long way east and west,
o.”

For the benefit of those who live outside of Kansas and
klahoma, and those who may never have chanced to meet an
rkansas Citian, it may be mentioned that their headquarters
-and there are 11,253 of them reported in the 1920 census—
located just three miles from the Oklahoma state line in
uthwestern Cowley county, which is about one-third of the
ate’s length east and west from the east Kansas boundary.
See figure 1.) It is thus located in the midst of a prosperous
d growingly wealthy part of the great Midcontinent region
hich has witnessed so rapid a development in the last few
ecades.

At the request and with the coöperation of the Chamber of
ommerce of Arkansas City, the State Geological Survey has
ade a special examination of the country immediately ad-
acent to Arkansas City in order to determine in advance, so
ar as possible, the natural resources which may contribute
arther to the development of the city, and to indicate the
mitations which may exist in the possibilities of utilization
f certain of the local resources. This bulletin records the re-
ults of these investigations and represents a type of com-
unity study which, it is believed, may advantageously be con-

ducted in many parts of our state. It may be pointed out in this connection that definite scientific information along any line affecting community or state interests is very valuable, even though in some particulars it may be negative; for it is, of course, quite as important to save money which might be uselessly invested and to avoid failures, as it is to call attention to possible resources, the quality, quantity and exac nature of which has not previously been known.

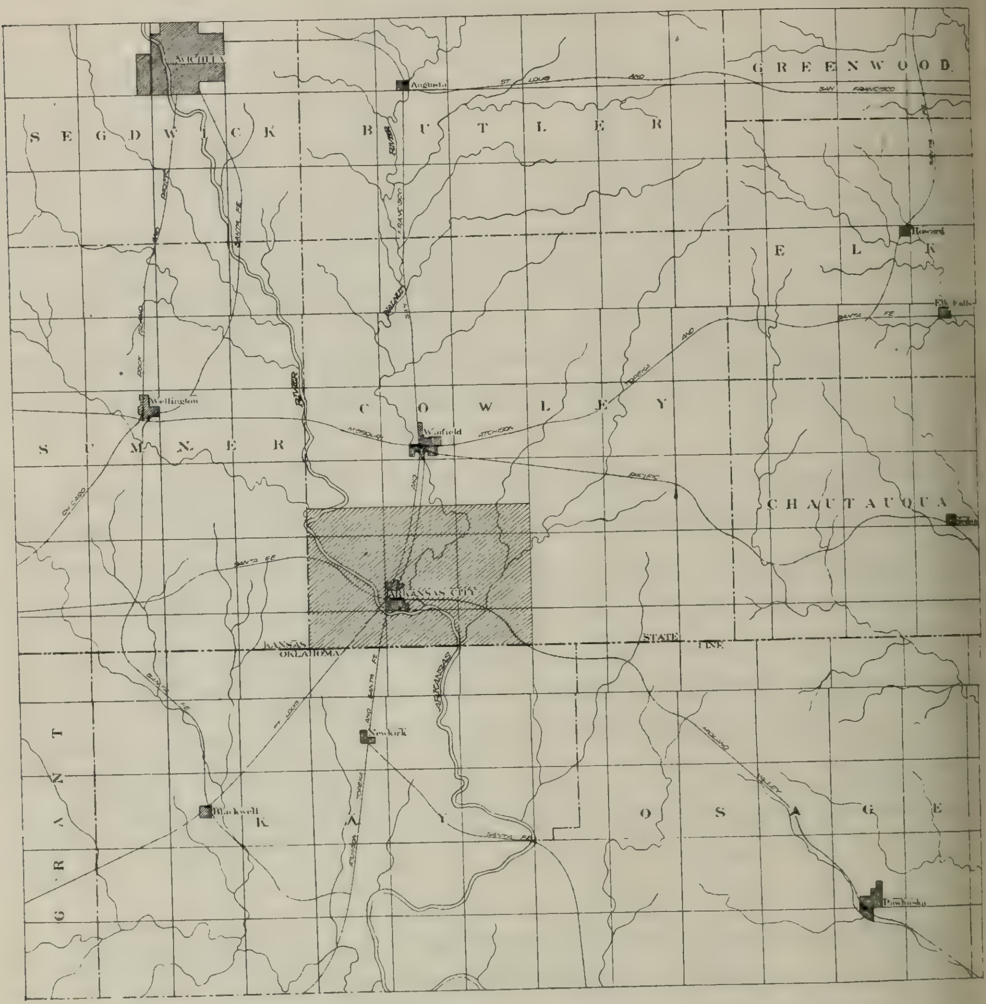


FIGURE 1. Location map of the Arkansas City district.

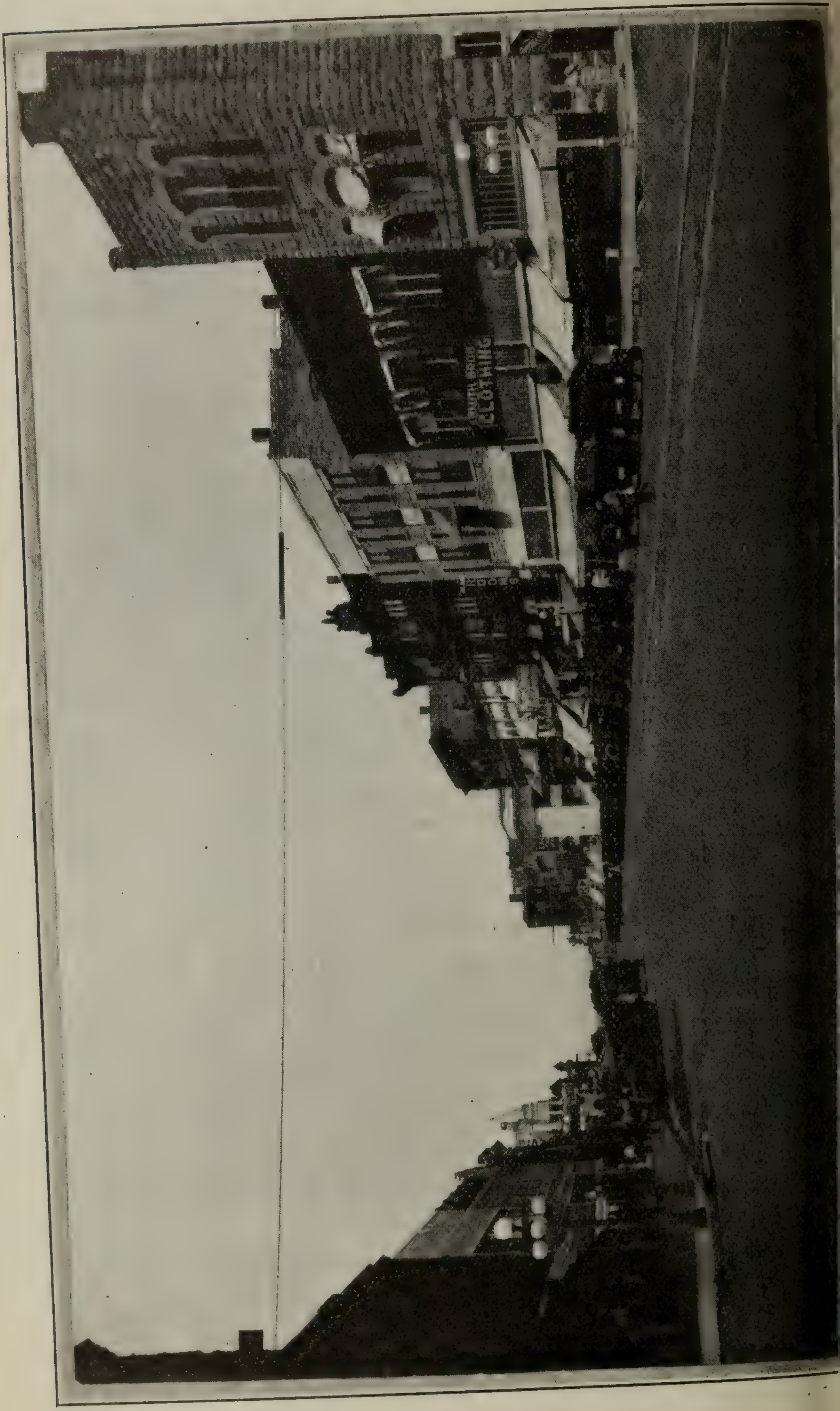
The area examined especially in the study of the Arkansa City district includes approximately 220 square miles, the location of which is shown on the index map (figure 1.) The fiel work was done by the writer, assisted by Mr. Lawrence Hay between June 10 and August 20, 1920. A considerable are was mapped with plane table and telescopic alidade in order t ine somewhat precisely the local structure of the rocks e possibilities of oil and gas development. All of the as examined with reference to other resources, such as naterials, sand and gravel deposits, brick clays, and materials of possible value. Special acknowledgment made of the assistance of Mr. O. B. Seyster, secretary Chamber of Commerce, for coöperation during the ss of the survey, and for information concerning the dement of the Arkansas City area; and to Mr. M. W. Baden, field, on the stratigraphy and general structural condin this part of the state. The Survey is indebted to the e Gas and Fuel Company for part of the information compiling the geological map of Cowley county.

THE ENVIRONMENT OF ARKANSAS CITY.

country about Arkansas City has a rolling topography, ef features of which are the rather abrupt escarpments by the outcrop of limestone beds, and the broad, level in the valleys of Arkansas and Walnut rivers. The esent topography is controlled by moderately hard outg limestones, which weather less readily than the inded shales. Arkansas City is well located with reference ography, being situated on a nearly flat river terrace at the junction of Arkansas and Walnut rivers.

largest stream is Arkansas river, which crosses the est corner of Cowley county from northwest to south- This stream, with Walnut river, which drains the area he north and empties into the Arkansas just east of sas City, drains practically all the area under discussion. southwest part of Cowley county contains many acres of aluable farm land, especially that in the valleys of the ers crossing the area, and Arkansas City is an important ial center, so that the area is rather thickly populated. which are most important are wheat, corn, alfalfa and Some of the Arkansas river bottom land is considered lly adapted for apple growing, and there are a number apple orchards within this area.

of the important contributing factors in the development agricultural resources of any area is the climate. Ac- to statistics compiled by the United States weather , from observations made at Winfield, the average


CLOTHING

l precipitation in this area from 1894 to 1917, inclusive,
1.79 inches. The highest average for any month during
eriod was 5.11 inches, in June, and the lowest 0.99 inch,
uary. For the twenty-year period ending with 1917 the
ge annual temperature was 56.5 degrees Fahrenheit. The
t average was 33.1 degrees, in January, and the highest
legrees, in July. For this same period the average date
earliest killing frost in the fall was October 19, and for
st killing frost in the spring was April 15.

DEVELOPMENT OF THE ARKANSAS CITY DISTRICT.

April 7, 1870, the town of Cresswell was founded on the
nt site of Arkansas City, but only a few months later the
was changed to that by which the town is now known.
s located on relatively high land between Arkansas and
ut rivers, this topographic location affording excellent
al drainage and immunity from danger of possible floods.
ring the first fifteen years the greatest problem con-
ing the town was transportation. All provisions had to
eighted, first from Emporia and later from Wichita. Be-
the years 1875 and 1879, when the coming of the rail-
seemed impossible, the citizens considered the naviga-
of the Arkansas river as a means of getting products to
rom the town, but the shallowness of the channel and the
nce of numerous sand bars made this almost an impossi-
.

rough the efforts of a few energetic citizens, the Santa
ilroad became an assured fact in 1885. Lots were given
he site of the station and $10,000 was contributed toward
uilding. These citizens were also instrumental in locating
anta Fe shops in Arkansas City a few years later. Later
Missouri Pacific railroad built a line through Arkansas

ss than two years after the founding of the town a union
ch building was erected. To-day the town boasts of some
e finest church buildings in the state. A public school was
ed in Arkansas City when as yet it was only a few weeks
Four years later a substantial brick building was erected
named the First Ward school. The city now has four ward
ols, a fine high school and a junior high school. The

PLATE II. Views in Arkansas City business section.

it school plant is valued at $750,000, and the schools are g the best in the state.

1885 the Land Improvement and Water Power Company eted the canal connecting the Arkansas river northwest vn with the Walnut southeast of the city. For years this furnished power for a number of manufacturing establents, and at present is the source of power for the A. C. g Company and for the electric-light plant.

e same year saw the beginning of an important building ı Arkansas City, and a number of attractive buildings erected. The growth of the city was considerably de- however, by the opening of the "strip" in Oklahoma, and anic of 1893 caused a cessation of plans for the town's opment; but during the last few years growth has been more rapid than before. The growth in population since has been 49 per cent. Since 1912 Arkansas City has been ned by a commission form of city government.

kansas City is one of the important industrial centers of tate. Four oil refineries are located here: the Milliken any, the Kanotex, the National Oil Company, and the re natural-gas gasoline plant. The charging capacity of refineries combined is 12,100 barrels per day. The divieadquarters of the Santa Fe for south Kansas and north-)klahoma, and large shops, are important contributing rs to the growth and prosperity of the city. Two flour with a daily capacity of 2,400 barrels, are also located Some of the other industries include a candy factory, t-packing plant, and an ice plant.

GEOLOGY.

e rocks of Kansas, as classified on the basis of origin, beto the sedimentary group. Rocks of igneous origin have found in some deep wells, but do not outcrop at the surwithin the boundaries of the state. Sedimentary rocks hose composed of the transported fragments or particles ler rocks which have undergone disintegration. The chief cies of transportation are water, wind and glaciers. Mas such as gravel, sand and clay are carried as solid partiand after deposition may be consolidated to form conglom-, sandstone or shale. Other materials may be carried in ion and deposited to form limestone, salt or gypsum.

Sedimentary rocks are usually made up of beds or layers, called strata, which can easily be separated.

The rocks which appear at the surface in the state belong to the Mississippian, Pennsylvanian, Permian, Cretaceous and Tertiary geologic divisions, named in order from older to

Geologic section of the Kansas region.

SYSTEM.	Groups.	Formation.	Character of rocks.
Quaternary.	Recent.		Alluvium, dune sands.
	Pleistocene.	Wisconsin stage, Kansas stage.	Glacial deposits.
Unconformity.			
Tertiary. *Unconformity.*	Pliocene, Miocene.	Ogalalla.	Gravel, sand, clay.
Cretaceous.	Montana.	Pierre.	Shale.
	Colorado.	Niobrara, Benton.	Limestone, chalk, shale.
	Dakota.	Sandstone.	Sandstone, shale.
Unconformity.			
Comanchean. *Unconformity.*	Washita.	Kiowa, Cheyenne.	Sandstone, shale.
Permian.	Cimarron.	Greer, Woodward, Cave Creek, Enid.	"Red beds," sandstone, shale, dolomite, gypsum, salt.
	Big Blue.	Wellington, Marion, Chase, Council Grove.	Shale limestone.
Pennsylvanian.	Missouri.	Wabaunsee, Shawnee, Douglas, Lansing, Kansas City.	Limestone, shale, sandstone.
	Des Moines.	Marmaton, Cherokee.	Limestone, shale, sandstone.
Unconformity.			
Mississippian.	Chester. *Unconformity.*		
	Osage.	Warsaw, Keokuk, Burlington, Pierson.	Limestone.
	Kinderhook.		Limestone, shale.
Unconformity.			
*Ordovician.		Joachim, Jefferson City, Roubidoux.	Dolomite, sandstone, shale.
Unconformity.			
*Cambrian.		Gasconade, Proctor, Eminence, Potosi.	
Unconformity.			
*Pre-Cambrian.			Granite.

*Not exposed in Kansas.

TATE GEOLOGICAL SURVEY
OF KANSAS

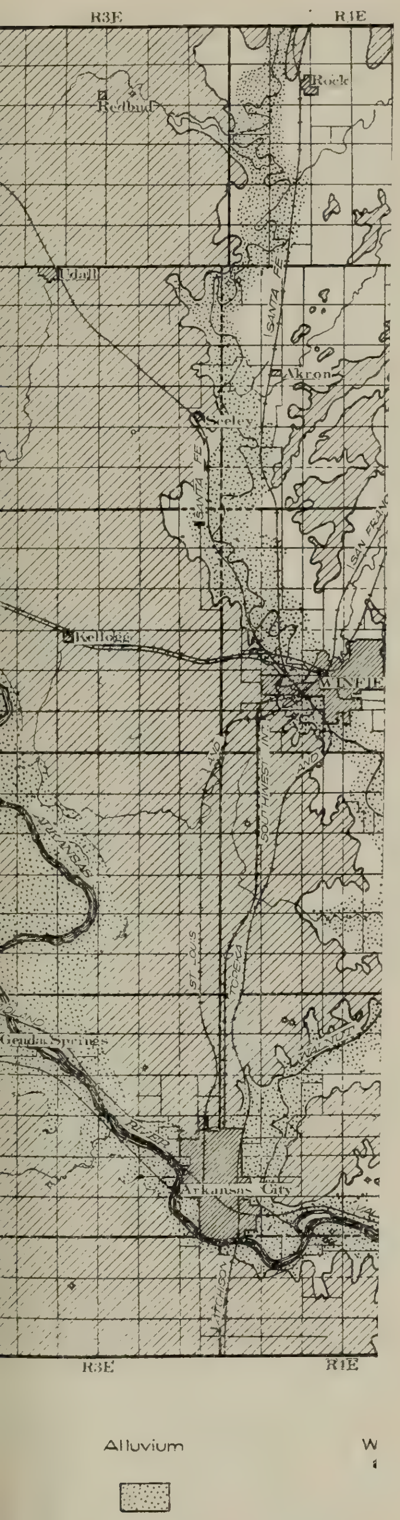


PLATE III. (

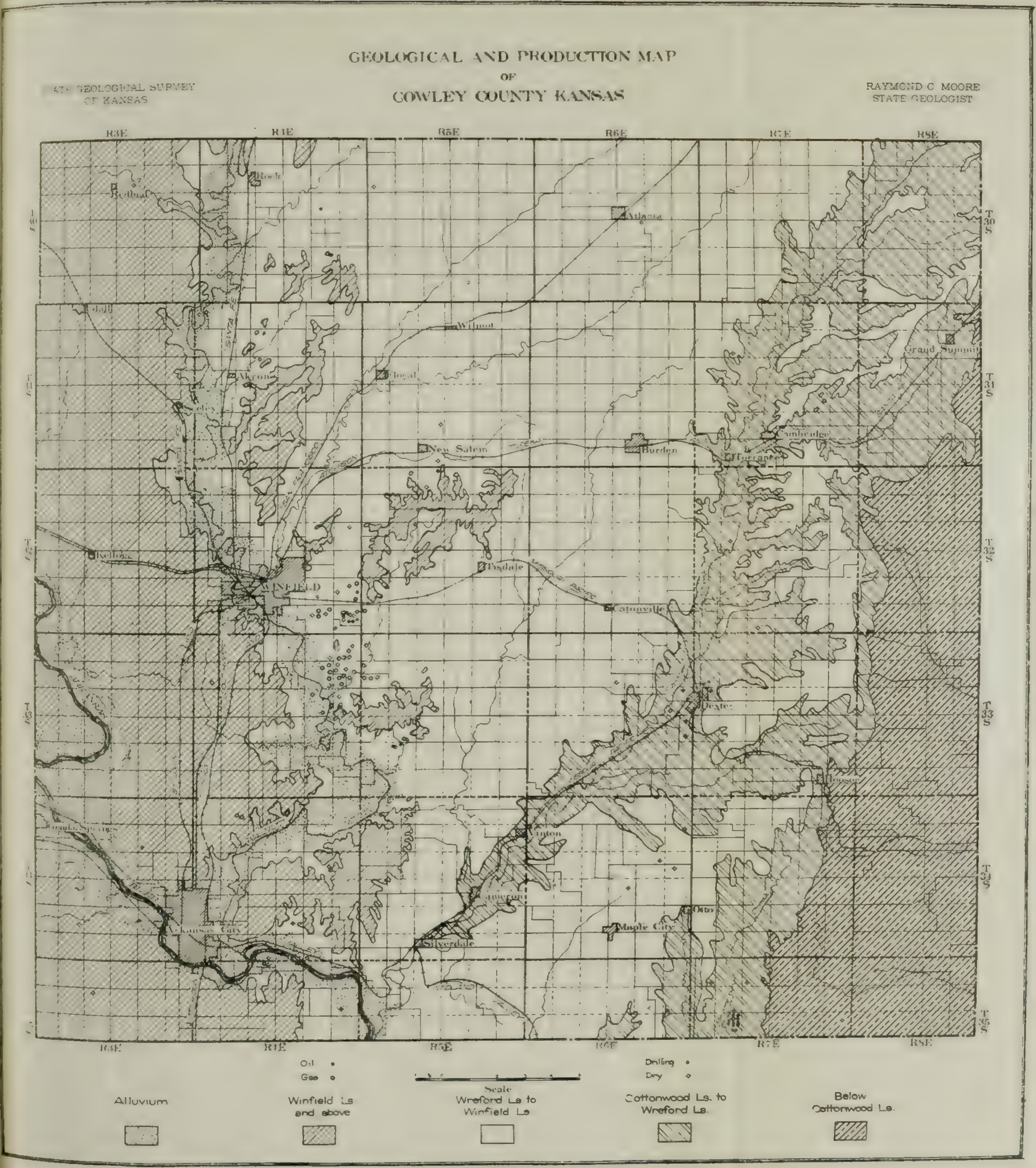


PLATE III. Geological and production map of Cowley county, Kansas.

ger. The older systems, of course, underlie the younger, ı were laid down upon them. Sedimentary rocks of sys- older than the Mississippian are known to underlie the from records obtained in drilling deep wells, and wells ıtral Kansas have encountered igneous rocks of pre-Cam- age. The accompanying table (page 12) gives the sub- ons of the various systems as recognized in Kansas.

ROCKS EXPOSED IN THE ARKANSAS CITY DISTRICT.

e rocks which are exposed in the Arkansas City district g to the lower group of the Permian system. Members ging to the Upper Pennsylvanian system outcrop in the rn half of Cowley county, but do not appear at the surface e area included in the Arkansas City district. The dis- tion of the formations which appear in Cowley county is n on plate III. The following table gives the divisions of ennsylvanian and Permian systems.

ın system.		
marron group.		
g Blue group		
Wellington formation (undifferentiated).	Exposed in Arkansas City district.	Exposed in Cowley county.
Marion formation.		
Pearl shale.		
Herington limestone.		
Enterprise shale.		
Luta limestone.		
Chase formation.		
Winfield limestone.		
Doyle shale.		
Fort Riley limestone.		
Florence flint.		
Matfield shale.		
Wreford limestone.		
Council Grove formation.		
Garrison shale and limestone.		
Cottonwood limestone.		
ylvanian system.		
issouri group.		
Wabaunsee formation.		
Eskridge shale.		
Neva limestone.		
Elmdale shale.		
Americus limestone.		
Admire shale.		
Emporia limestone.		
Willard shale.		
Burlingame limestone.		
Shawnee formation.		
Douglas formation.		
Lansing formation.		
Kansas City formation.		
es Moines group.		
Marmaton formation.		
Cherokee shale (undifferentiated).		

As shown in the table, the rocks exposed in the Arkansas City district belong to the Chase, Marion and Wellingto formations of the Big Blue group of the Permian. This group the lower division of the Permian, consists entirely of marin sediments, divided, in the order of their quantitative importance, into shale, limestone, and sandstone. These formation will be discussed in the order of their appearance as the are is crossed from east to west, or from oldest to youngest.

CHASE FORMATION.

Members belonging to the Chase formation are the oldes and lowest rocks, stratigraphically, which appear in the A kansas City district, and occupy approximately the easter one-half of the area. (See plate III.) The formation contai a number of massive, cherty limestone members, which, on a count of their resistance to erosion, form one of the mo prominent topographic features of central Kansas, the Fli Hills. The Chase formation has a total thickness of about 2 feet.

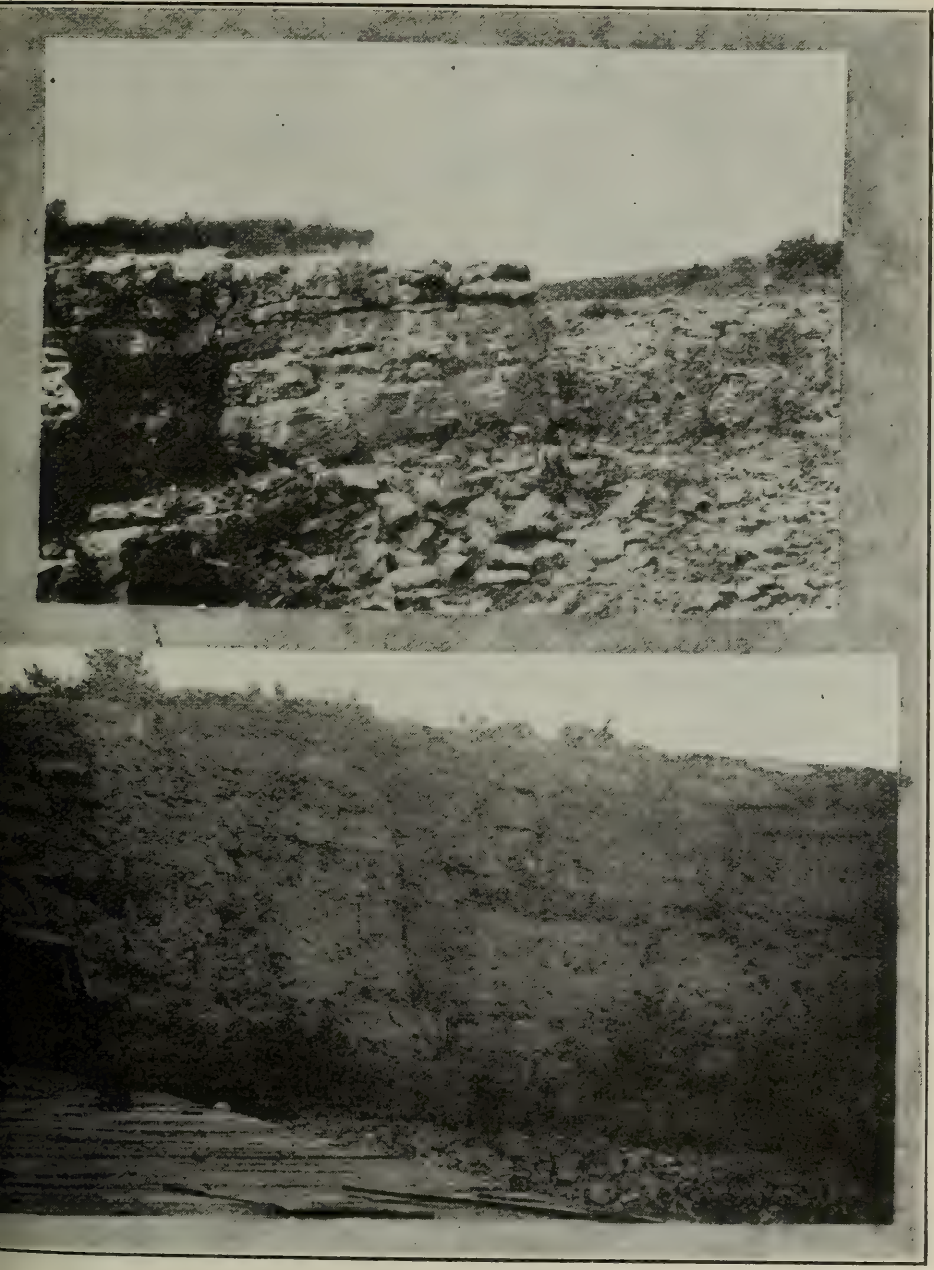
The lowest subdivision of the Chase formation is the Wr ford limestone, consisting in its type locality of 35 to 50 fe of massive limestone and chert. The outcrop of the Wrefo forms a rather prominent escarpment across eastern Cowl county, and extends westward along Grouse creek to ne Silverdale in the eastern part of this area. In parts of sout ern Kansas the Wreford becomes imperfectly solidified a weathers in places to a reddish-brown, very porous rock. T thickness of the Wreford in parts of Cowley county is not m than 15 to 20 feet.

Overlying the Wreford is the Matfield shale member, wh includes from 60 to 70 feet of variously colored shales a thin, interbedded limestones. The outcrop at the surface not wide.

The Florence flint consists of about 20 feet of very fli limestone, a number of layers being composed wholly of fl The member is resistant to erosion, and with the overly Fort Riley limestone forms a prominent escarpment.

The Fort Riley limestone includes about 40 feet of mass buff limestone with thin, interbedded shaly strata in the up part. Near the center of the member are one or two v massive beds, which form a conspicuous bench at the outc

Fort Riley limestone and the Florence flint outcrop in the ansas City district, the nearest exposure being in a large rry about five miles east of town in sec. 1, T. 35 S., R 4 E., re the Fort Riley measures 40 feet in thickness and con- of massive buff limestone, with a little shale in the upper ion. (See plate IV.) The Florence flint is not so well ex- d, but is recognizable immediately below the Fort Riley.



LATE IV. *Above:* Outcrop of Herington limestone north of Arkansas *Below:* Exposure of Fort Riley limestone in quarry in sec. 1, S., R. 4 E.

Another good exposure of the Fort Riley is found in the quarry
about two miles north of Silverdale.

The Doyle shale member overlies the Fort Riley limestone
and consists of variously colored shales, with thin, interbedde
shaly limestone beds. In its type area the Doyle shale is abou
60 feet thick, but is thinner in the Arkansas City district, th
thickness in some localities being less than 30 feet. It i
thicker in the northern part of the area, and contains on
rather persistent limestone bed near the center, which is abou
a foot thick.

The Winfield limestone is the top member of the Chase fo
mation. In areas farther north the Winfield is a very chert
limestone, but in the vicinity of Arkansas City this chara
teristic is not so prominent. In this area the member is abo
15 feet thick. It has a very porous texture near the top, a
the upper portion is also fossiliferous, containing numero
crinoid stems and brachipods. The Winfield ranges in col
from gray to yellow. It forms an easily traceable escarpme
throughout this area, and was used very largely in determi-
ing the rock structure of the area. The Winfield is typica
exposed near Winfield, 15 miles north of Arkansas City, a
its outcrop extends entirely across Cowley county from nor
to south. (See plate III.) An excellent exposure may
seen about five miles east of Arkansas City at the top of wh
is locally known as Horseshoe Hill. (See plate V.)

MARION FORMATION.

The Marion formation is clearly defined from the beds ab
and below it. It lacks the cherty character of the Chase f
mation below, and is distinguished from the overlying W
ington formation by its limestone content, which is practica
absent in the higher formation. The outcrop of the Mario
characterized by broad, rather gentle slopes, in direct contr
to that of the Chase formation. The Marion formation ha
total thickness of about 150 feet and has been divided i
four stratigraphic subdivisions.

Over a considerable portion of central Kansas the I
limestone forms the basal member of the Marion format
It is well exposed in the vicinity of Marion and near Her
ton, where it is a cellular, soft, gray limestone about 15
thick. The member becomes much thinner to the south an

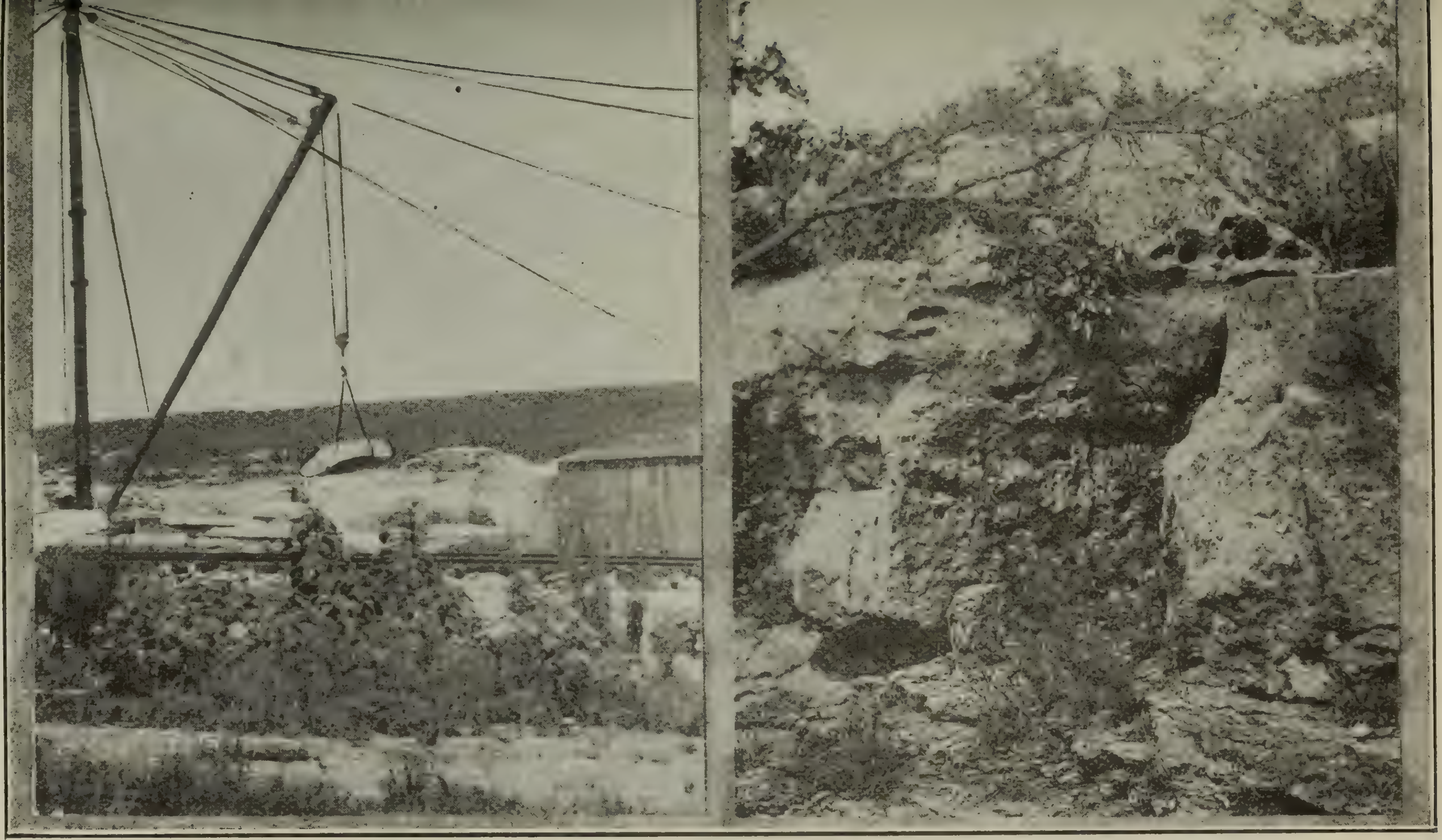


PLATE V. *Left:* Quarry in Fort Riley limestone north of Silverdale. *Right:* Exposure of Winfield limestone at Horseshoe Hill.

barely recognizable in the area about Arkansas City. In some places it is represented by two or three feet of soft, fossiliferous, gray limestone lying immediately above the Winfield, but it is not present over most of southern Cowley county.

The Enterprise shale member consists of variegated shale, green, yellow and maroon in color. It has a thickness in the Arkansas City district of from 45 to 65 feet.

Succeeding the Enterprise shale is a buff to gray, massive limestone, which is rather well exposed in the vicinity of Arkansas City. From typical exposures in the vicinity of Herington, this member has been named the Herington limestone. As exposed about one mile north of Arkansas City, the Herington is about 8 to 10 feet thick, is rather massive, and in places is very sandy. (See plate IV.) A few miles south of Arkansas City, south of Arkansas river, the Herington consists o two limestone beds, separated by 12 to 15 feet of limy shale. The lower limestone is about 3 feet thick, light gray in color rather hard, and contains a few chert nodules. The uppe ledge is about 8 feet thick, buff to light gray in color, thi bedded, and is a good deal softer than the lower ledge.

A succession of green, blue and red shale, termed the Pear shale member, overlies the Herington limestone. On accoun of the lack of resistance of the overlying members, outcrops o the Pearl shale are very uncommon. The thickness of th member is estimated to be 70 feet. There are a few more o less persistent limestone members in the upper portion of th Pearl shale, which mark the line of division between th Marion and Wellington formations. These beds have a rathe porous texture and are not resistant to weathering, and co sequently do not form prominent escarpments.

WELLINGTON FORMATION.

The Wellington formation is the highest formation whic is exposed in the Arkansas City district, the lower part of th formation outcropping in the western part of the area near th Sumner county line. The Wellington consists of a thick su cession of blue, gray and yellow shales, with a very few no persistent limestone beds. The total thickness of the Wellin ton is estimated to be over 500 feet, but the thickness of th portion exposed in this area is much less. Owing to the la of any distinct stratigraphic marker between the Wellingt

Marion formations, the exact eastern boundary of the lington has not been determined.

QUATERNARY DEPOSITS.

addition to the stratified rocks discussed, there are in area unconsolidated sediments belonging to the Quater- system. These deposits are the river alluvium in the eys of the Arkansas and Walnut rivers and at least one el deposit of Pleistocene age. This deposit is located 3 s north of Silverdale and is a Pleistocene river deposit. onsists largely of a chert gravel, probably having its origin he cherty members of the Chase formation. The deposit rs several acres of ground and is about 8 feet thick. (See e VI.)

ONCEALED ROCKS IN THE ARKANSAS CITY DISTRICT.[1]

formation concerning the rocks which underlie the Arkan- City district, but which do not appear at the surface any- re in the area examined in this survey, may be obtained n two sources, one from well records, and the other from rvations made at the outcrops outside the area. From a ly of well logs it is known that the lower formations of the mian system and the Pennsylvanian system of Kansas un- ie all of southwest Cowley county. A number of wells e been drilled into the Mississippian, so that at least a part his system is present. On account of the general west dip he rock strata in eastern Kansas, these formations which present beneath the surface in the Arkansas City district crop farther east where the overlying rocks have been led.

f a well were drilled near Arkansas City, starting in the field limestone member, it would pass through about 200 of limestone and shale belonging to the Chase formation, ch outcrops in the area east of Arkansas City. The next er formation which would be encountered is the Council ve formation, the basal division of the Permian. The rage total thickness of the Council Grove is about 150 feet. onsists of an upper member of shale and thin, interbedded estones, and a lower, resistant limestone member at the e. After passing through the Council Grove formation the

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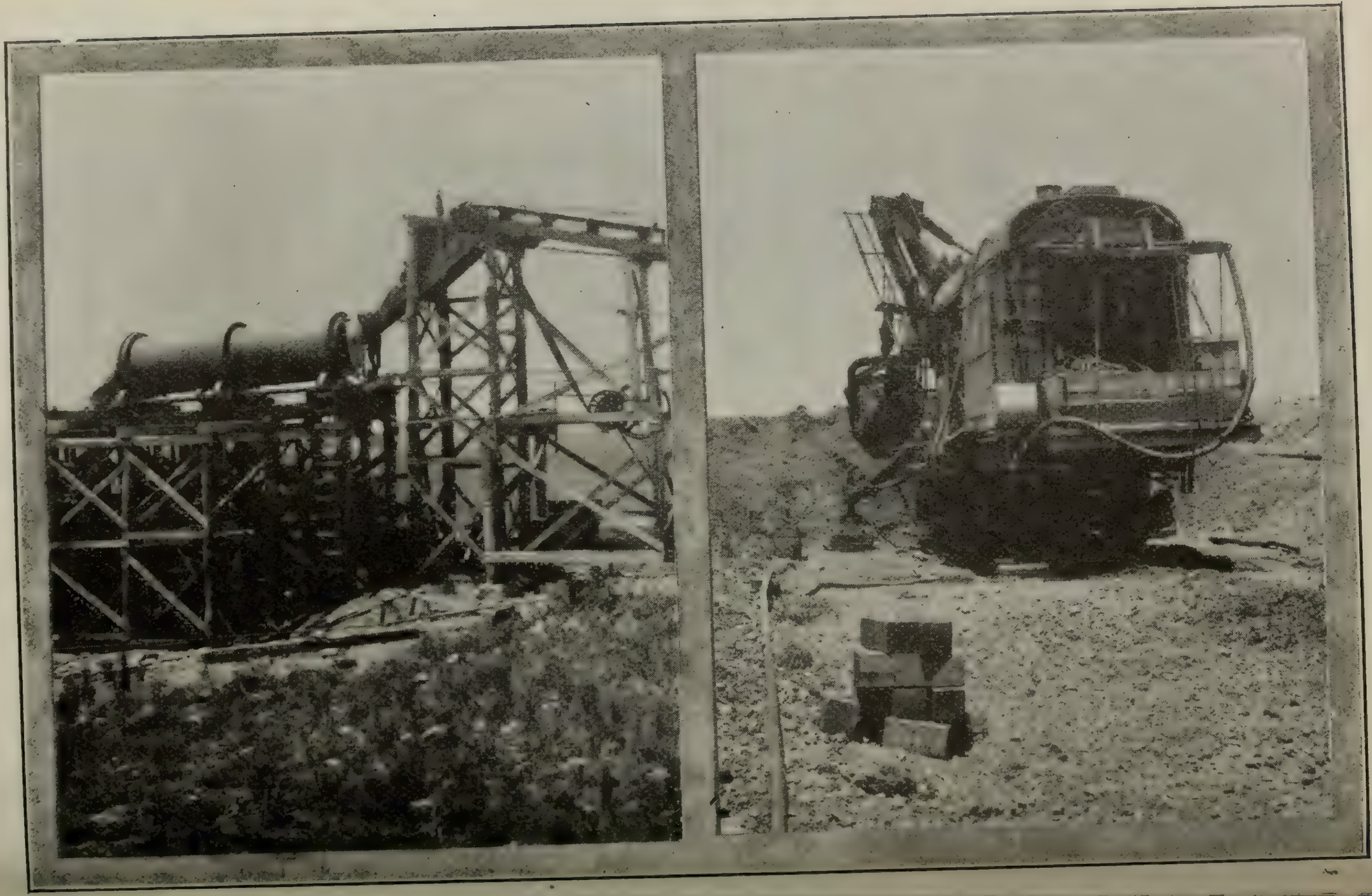
[1] For detailed discussion of the geology of Kansas, see Moore, Raymond C.; Oil and esources of Kansas; Geology of Kansas: Geol. Survey of Kansas, Bull. 6, pt. 2; 1920.



ould enter the upper members of the Pennsylvanian sys-
The total thickness of the Pennsylvanian in this area is
han 3,000 feet. As observed in the area of its outcrop in
rn Kansas, the Pennsylvanian consists of a thick series
ernating shale and limestone members with irregular beds
dstone and some beds of coal. From a quantitative stand-
the shales are the most important of the Pennsylvanian
. The limestones are mainly light-colored, fossiliferous,
rained rocks, many of the beds being also very cherty.
d in order from top to bottom, the following formations
be encountered in the well: Wabaunsee, Shawnee,
as, Lansing, Kansas City, Marmaton, and the Cherokee
(See table, page 12.) Of these, the Wabaunsee is the
ne which appears at the surface in Cowley county.
mbers belonging to the Wabaunsee formation, which has
l thickness of about 500 feet, outcrop in the southeastern
of the county. The Wabaunsee consists of alternating
one and shale beds, the top member being the Eskridge
which immediately underlies the Cottonwood limestone,
ne basal member the Burlingame limestone.
succeeding lower members of the Pennsylvanian as they
be encountered in a well are exposed in the same order
state is crossed from west to east from the eastern edge
wley county. The Cherokee shale, the basal formation
Pennsylvanian, which should be encountered in a well
Arkansas City at a depth of about 3,100 feet, is exposed
southeastern part of the state, covering most of Chero-
nd parts of Crawford, Labette and Bourbon counties.
ormation contains numerous sandstone beds which have
n productive of oil and gas in areas where it is covered.
lition to the sands in the Cherokee, there are other very
sands found in higher formations of the Pennsylvanian.
of the more important of these are in shale members of
armaton and Kansas City formations.
mediately below the Cherokee shale, the Mississippian
n, commonly spoken of as the "Mississippi lime," would
countered. It was found at a depth of 3,270 feet in the
nd well south of Arkansas City. The Mississippi lime
osed at the surface in Kansas in a very small area in
outheast part of Cherokee county, in the extreme south-
art of the state. It consists chiefly of a crystalline lime-

stone containing an unusual amount of hard chert, and contains at least two sand "breaks" which have been productiv of oil in southern Kansas and Oklahoma. The total thicknes of the Mississippian in Kansas is estimated at about 350 t 400 feet.*

ECONOMIC GEOLOGY.

The natural resources of the Arkansas City district are o and gas, clay, road materials, cement, building stone, sand an gravel, and water supply.

OIL AND GAS.

The Arkansas City district is centrally located with refe ence to a number of producing fields in both Kansas and Okla homa. (See figure 2.) The nearest fields are those in Kay an Osage counties, Oklahoma, and in Chautauqua, Elk and Butl counties, Kansas. There is some production in Cowley count near Dexter and Maple City in the eastern part, and near Wi field in the central part of the county. (See plate III.) southern extension of the Fox-Bush pool of Butler coun extends a short distance into Cowley county on the north.

DEVELOPMENT.

The Dilworth field, a northern extension of the Blackw field, is located about 16 miles southwest of Arkansas City Oklahoma. The field was opened about 1912 and developme has continued intermittently up to the present time. The de production in the Blackwell field occurs at a depth of abo 3,300 feet. There are a number of producing sands at sh lower depths, a fairly good gas sand being found at abo 750 feet.

In the field located northwest of Newkirk, about 12 mi south of Arkansas City, production has been encountered the Mississippi lime at a depth of about 3,400 feet. There also considerable production in the vicinity of Ponca Ci development work having been started in this field as ea as 1904.

Chautauqua county, east of Cowley, has been an import oil- and gas-producing area for a good many years. Prod tion in the Peru and Sedan fields is encountered in three sa —the Bartlesville, Peru and Red—found there at depths ut 1,200, 1,000 and 950 feet, respectively. Most of the oil ls in Chautauqua county are small producers, but are noted their long life, some of the wells having produced for as as 12 or 15 years.

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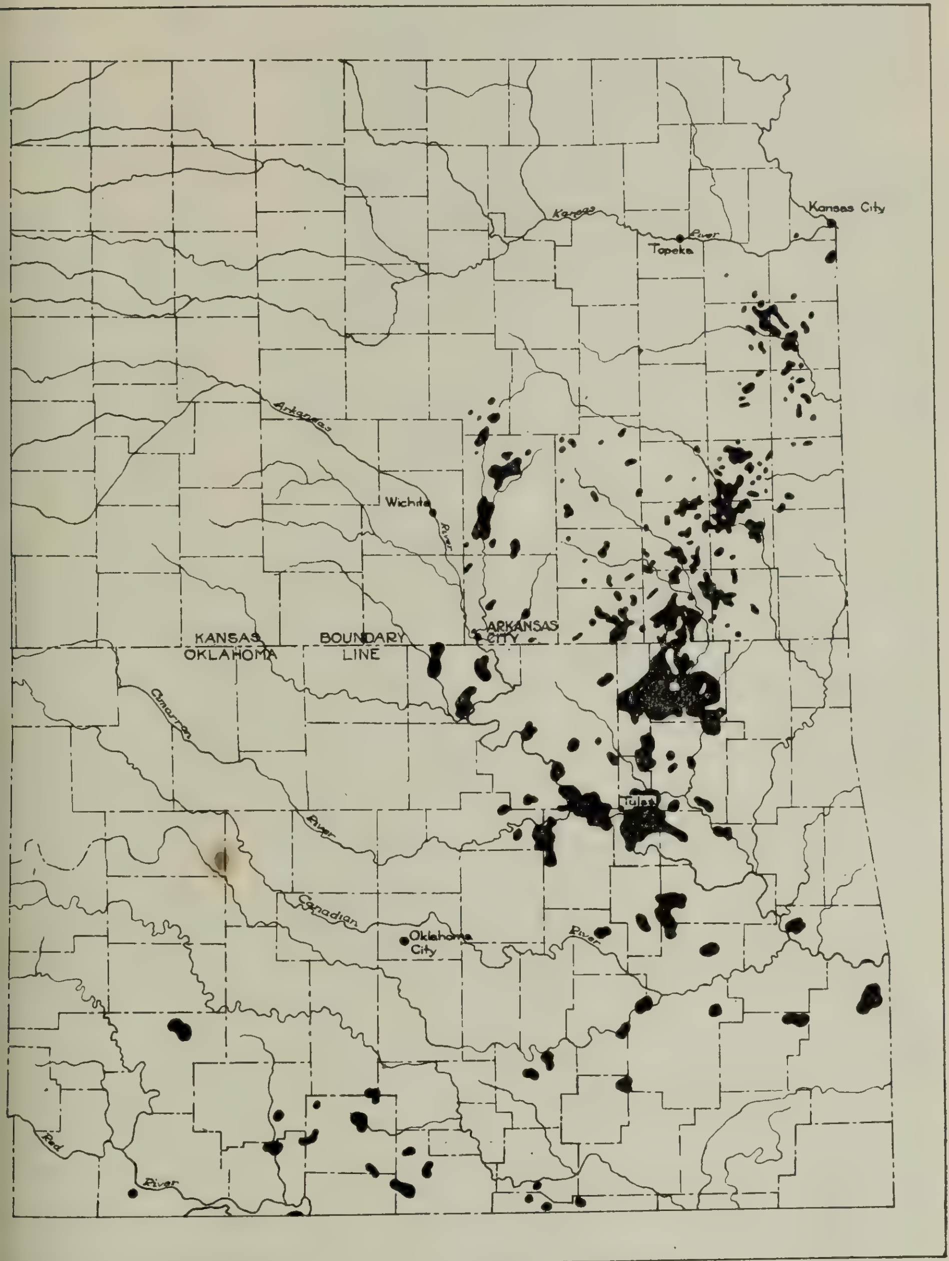
* It is possible, indeed probable, in some cases that these "breaks" are below Mississippian.—STATE GEOLOGIST.



RE 2. Map showing location of Arkansas City with reference to the oil and gas fields of Kansas and Oklahoma.

he area of largest oil and gas production in Kansas is in ler county, just north of Cowley. Oil was first discovered ommercial quantities near Augusta in 1914, although the nty had been producing gas for a number of years previous.

Most of the production in the Butler county fields is found in sands varying in depth from 1,700 to 2,700 feet. In the Fox-Bush field, in the southern part of the county, the main producing horizon is the Burgess sand, found at a depth of about 2,700 feet.

There are a number of small oil and gas fields in Cowley county. One area of considerable importance is located about seven miles southeast of Maple City, in sec. 17, T. 35 S., R. 7 E. Eleven wells have been drilled in the northeast quarter of this section, all of which are producing. The first well was drilled in 1917. One well is producing gas at the rate of six million cubic feet per day from a sand at 1,400 feet. Another well was drilled to the Bartlesville sand at a depth of 2,665 feet and came in at about 200 barrels. The remaining wells get their production from the Peru sand at a depth of about 2,000 feet. The average initial daily production of the ten oil wells was about 100 barrels and the settled daily production about 80 barrels per day.

An area in which considerable gas and oil is being produced is located southeast of Winfield. The production here is obtained largely from sands from 1,400 to 1,700 feet in depth. A very good gas sand is found in this area at a depth of from 650 to 700 feet.

There are a few wells near Dexter, in eastern Cowley county, some of which have been producing oil for several years. Production in this area is found at a depth of about 2,200 feet, from what is reported to be the Bartlesville sand.

There has been some development work within a radius of a few miles of Arkansas City, some production, principally gas, being encountered north of town as early as 1906. These wells, however, have been abandoned. There are several fairly good gas wells about 4 miles southeast of town in sec. 4, T. 35 S., R. 4 E. These wells are producing from a sand at a depth of about 1,925-1,950 feet, which probably belongs to the Chanute or Cherryvale shale member of the Kansas City formation.

A well of considerable importance in this district is the Marland well, located about 5½ miles southeast of Arkansas City, in sec. 16, T. 29 N., R. 3 E., Kay county, Oklahoma. This well was brought in at 700 barrels in May of 1920, and has settled to about 300 barrels. The production is obtained from a sandy lime in the Mississippian at a depth of 3,635-3,669 feet. The Mississippi lime was encountered at 3,270 feet.

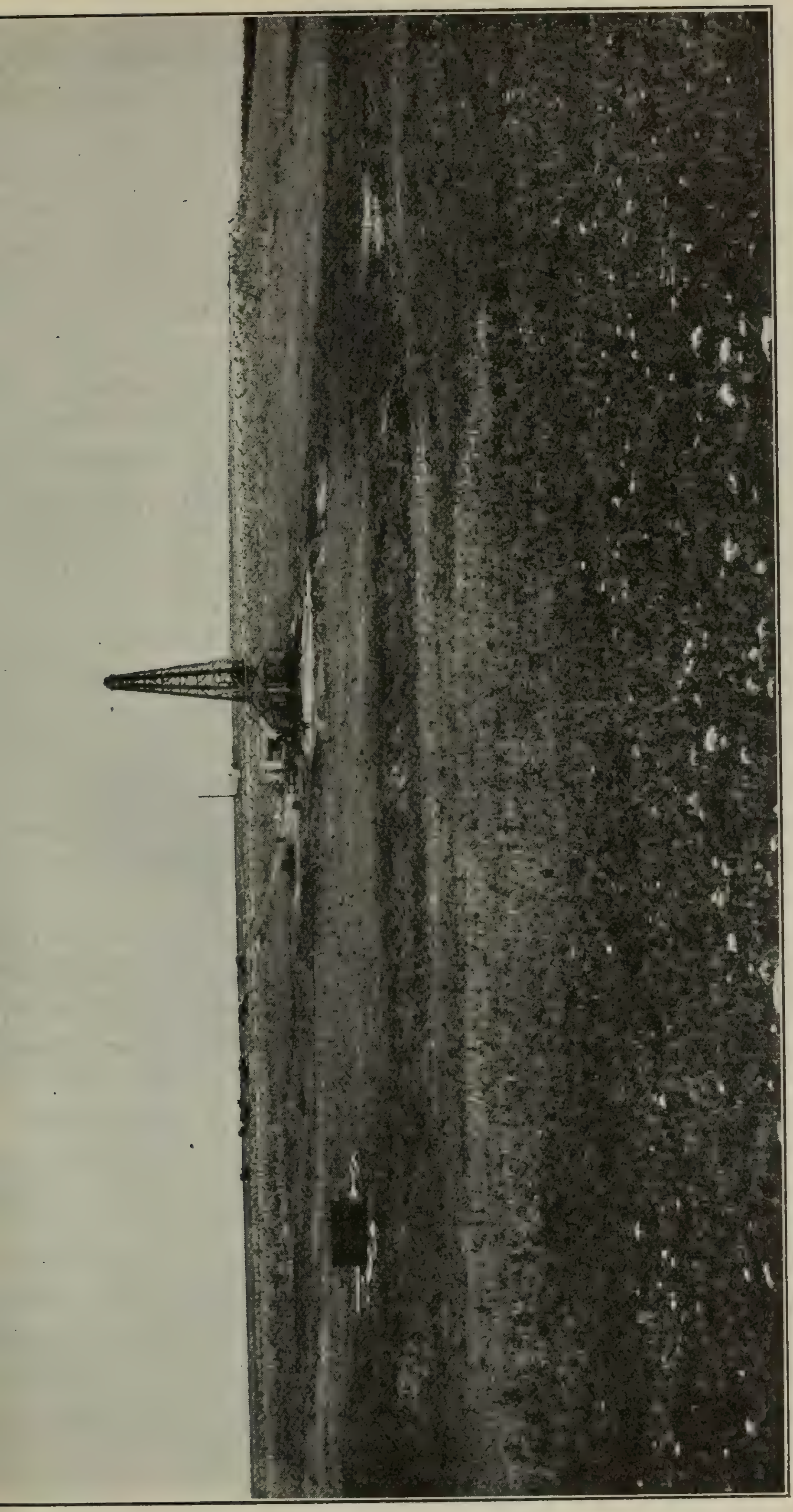


PLATE VII. Oil well in sec. 16, T. 29 N., R. 3 E., Kay county, Oklahoma, 5½ miles southeast of Arkansas City, showing also the outcrop of the Winfield limestone.

STRUCTURE.

In this area, as in other areas in the Midcontinent field, geologic structures such as anticlines, domes and terraces are most favorable for the accumulation of oil and gas. It should be remembered, however, that the location of a well on favorable geologic structure does not guarantee the finding of oil or gas. Nevertheless, such a location does greatly diminish the risk attached to oil and gas prospecting. A number of conditions may exist beneath the surface, any one of which may cause a structure to be unproductive. There may be no porous stratum or "sand" capable of holding commercial deposits of oil or gas, and even if such a porous stratum is present it may be dry. The sand may be so tightly cemented that there is very little pore space, and consequently oil and gas cannot be present in large quantities. There is also possibility that the oil- and gas-bearing horizons do not conform to the surface formations, surface structure not being precisely reflected, therefore, in the lower strata. This latter condition is of importance in the Arkansas City district, owing to the fact that a part of the production may be expected from the Mississippi limestone, and there is a known unconformity between the Mississippian and the overlying Pennsylvanian formations. However, experience has shown that Mississippian production follows surface structure in general rather closely.

A detailed structural examination was made in Townships 34 and 35, South, Range 3 East, with the aid of a telescopic alidade and a plane table. The strata in this area have a general dip a little south of west, which amounts on the average to about 30 feet per mile. This normal dip is interrupted in a number of places by small folds, which form domes, anticlines or synclines. The arrangement of these folded areas is not regular, but in general they appear to trend slightly east of north.

The geologic structure is shown on the map (plate VIII) by structure contours, which are imaginary lines connecting all points of equal elevation of the rock stratum. Since no single limestone bed is found over the entire area, it was necessary to secure elevations on two different beds, the Winfield and Herington limestones. The interval between these beds was rmined in a number of favorable localities and the elevas all reduced to a datum, the top of the Winfield limestone. elevations shown on the contour lines indicate height ve sea level, and the contour interval is 5 feet.

he largest and most favorable structure in this area is ted in secs. 3, 4 and 9, T. 35 S., R. 4 E. This structure has aximum east dip of 23 feet in a distance of about threerths of a mile. The north dip cannot be determined on acnt of lack of exposure in the broad valley of Arkansas river, it is probable that the structure closes on the north. Sevgas wells are located in the valley in the northeast quarter ection 4, which are thought to be on the north extension of structure. A dry hole was drilled in the southwest corner ection 4 to a depth of over 3,400 feet and was abandoned in Mississippi lime. As seen from the accompanying struce map, this well is located down on the west side of the icture. A well was drilled in the southwest quarter of the thwest quarter of section 3 to a total depth of 3,645 feet. s well encountered several gas sands, one near 1,400 and at 1,951, corresponding to those found in the producing wells in section 4, and also got an oil showing at 3,240-3,276 t. This test was located slightly east of the structure. e plate VIII.) Probably the best location for a deep test of s structure would be the center of the north line of the theast quarter of section 4.

South of the structure just described, in the eastern part of tions 9 and 16, is another structure, smaller than the first, ring an east dip of only a little over 10 feet in about onef mile. The exact outline of this structure could not be ermined on account of the lack of exposures in parts of secns 15 and 16, but it is very nearly as shown on the struce map. Although this structure is not as large as that to north, it is probably worth testing. It is interesting to e that this structure, with the one in sections 4 and 9, are alst in line north and south with the structure on which the rland well is located, just a mile south of the state line, d it seems very probable that there is some connection beeen them.

There is a terrace-like structure in secs. 13 and 14, T. 34 S., 4 E. The maximum east dip here is not over 5 feet, but the at" covers an area of about a square mile. On the north of

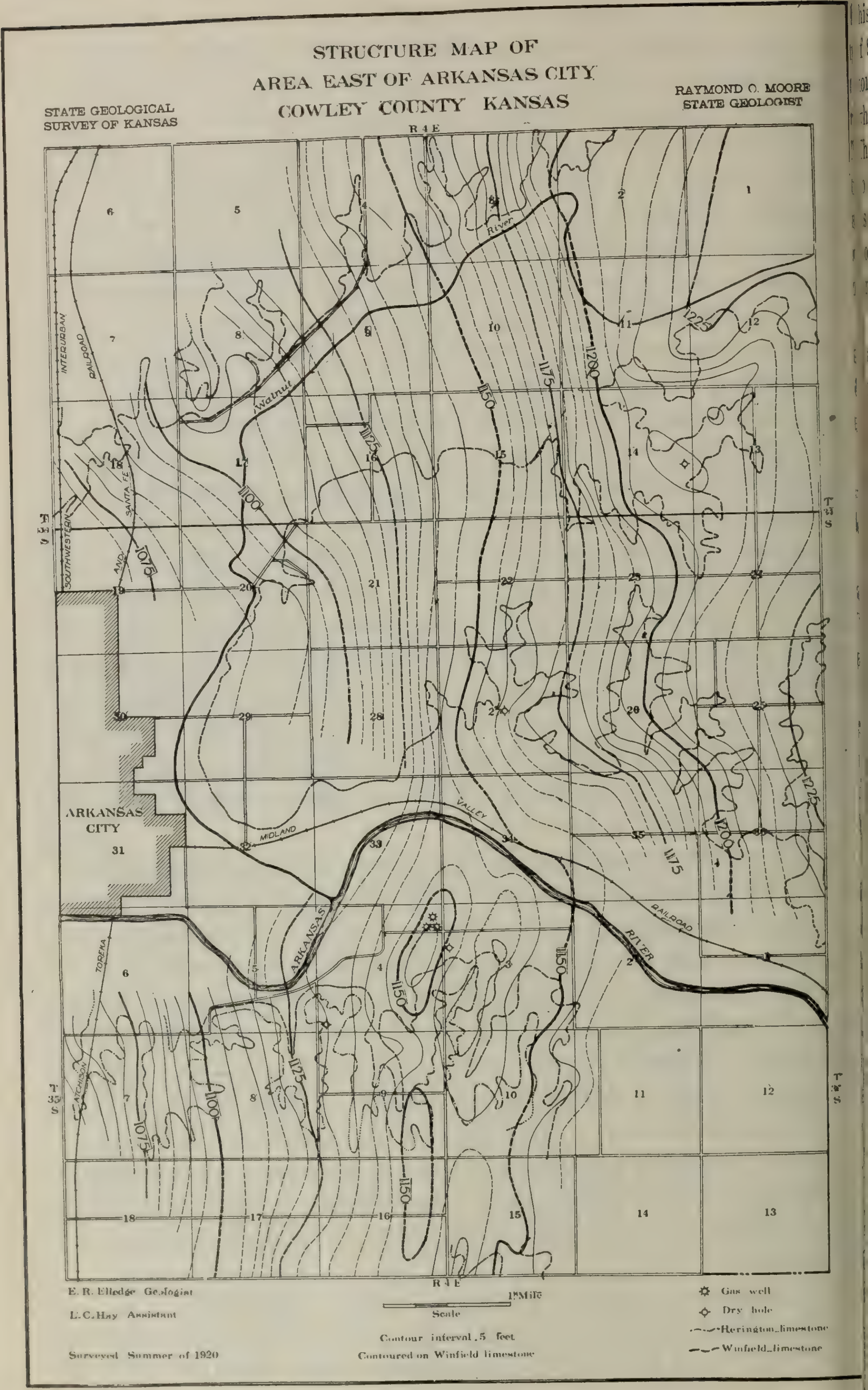

STRUCTURE MAP OF
AREA EAST OF ARKANSAS CITY
COWLEY COUNTY KANSAS
STATE GEOLOGICAL SURVEY OF KANSAS
RAYMOND C. MOORE STATE GEOLOGIST
R 4 E
T 34 S
T 35 S
Walnut
River
ARKANSAS
RIVER
ARKANSAS CITY
INTERURBAN RAILROAD
SOUTHWESTERN AND SANTA FE
MIDLAND VALLEY RAILROAD
ATCHISON TOPEKA
1075
1100
1125
1150
1175
1200
1225
E. R. Elledge Geologist
L. C. Hay Assistant
Surveyed Summer of 1920
1 Mile
Scale
Contour interval 5 feet
Contoured on Winfield limestone
Gas well
Dry hole
Herington limestone
Winfield limestone

PLATE VIII.

; terrace, in sections 11 and 12, is a "nose" with an east dip) feet and a south dip of 20 feet. A well was drilled in the theast corner of the southeast quarter of section 14 on it is probably as favorable a location as any on the terrace. s well was abandoned, but is reported to have been drilled a depth of less than 2,000 feet, so cannot be considered a thorough test of the structure. A location near the thwest corner of the southwest quarter of section 12 should ve whether or not the "nose" will prove productive.

'here is also evidence of a small dome just north of Arsas City, in sections 8 and 17. On account of the character he Herington limestone in this area, it was not possible to ermine its exact size and shape. This is the area in which imber of gas wells were drilled several years ago, but so far s known, no deep test has ever been made. The fact that gas wells were found here makes a deep test very desirable. t is reported that a favorable structure has been mapped t east of Silverdale and that a well is being drilled on it. s area was not mapped in detail, so its exact location and are not known.

lthough several dry holes have been drilled in the area un- discussion, it will be seen from the structure map that, h one exception, they were not located on the most favor- structures, and consequently do not condemn the area. well drilled in sec. 14, T. 34 S., R. 4 E., was not drilled sufficient depth to be a thorough test of the structure on ich it is located. The fact that a number of good gas wells 'e been drilled on the structures discussed, and that the rland well, which has a settled production of 300 barrels, is ated just a mile from the southern edge of this area, and t there are several producing areas located within 25 miles Arkansas City, make desirable, in the writer's opinion, the ing of these structures. In order to make these tests thor- h, the wells should be drilled at least to the second "break" the Mississippian. Since recent subsurface investigations[2] Kansas and Oklahoma indicate that much important pro- tion is coming from rocks even older and lower than the ssissippian, thorough testing of the Arkansas City struc- es should require drilling deeply into or through these pre- ssissippian rocks.

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[2] Aurin, F., Clark, G. C., and Trager, E.; Pre-Pennsylvanian stratigraphy of the ontinent region: Bull. Am. Assn. Petroleum Geol., vol. 5, No. 2; March, April, 1921.

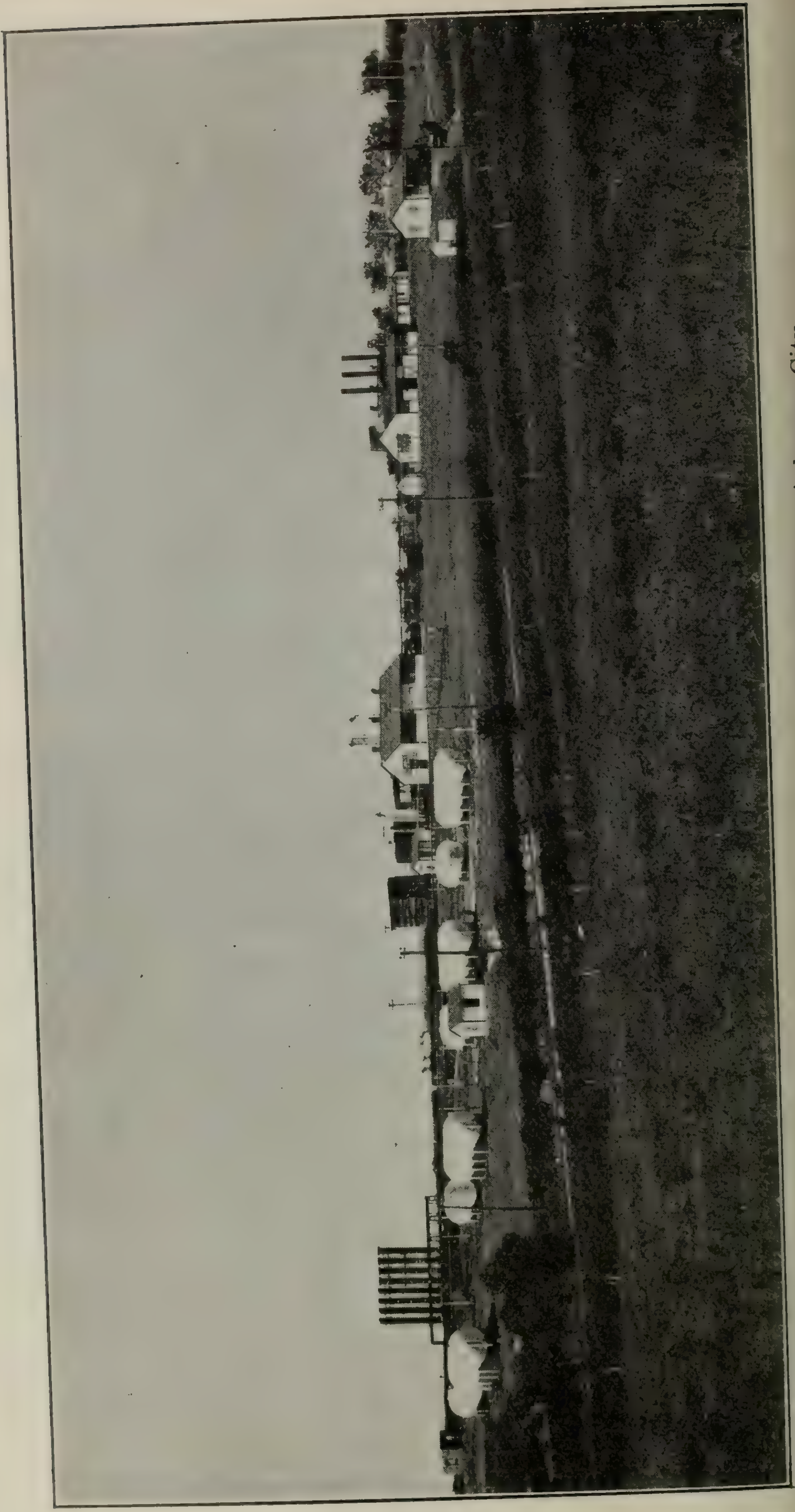


PLATE IX. The Empire natural-gas gasoline refinery at Arkansas City.

REFINERIES.

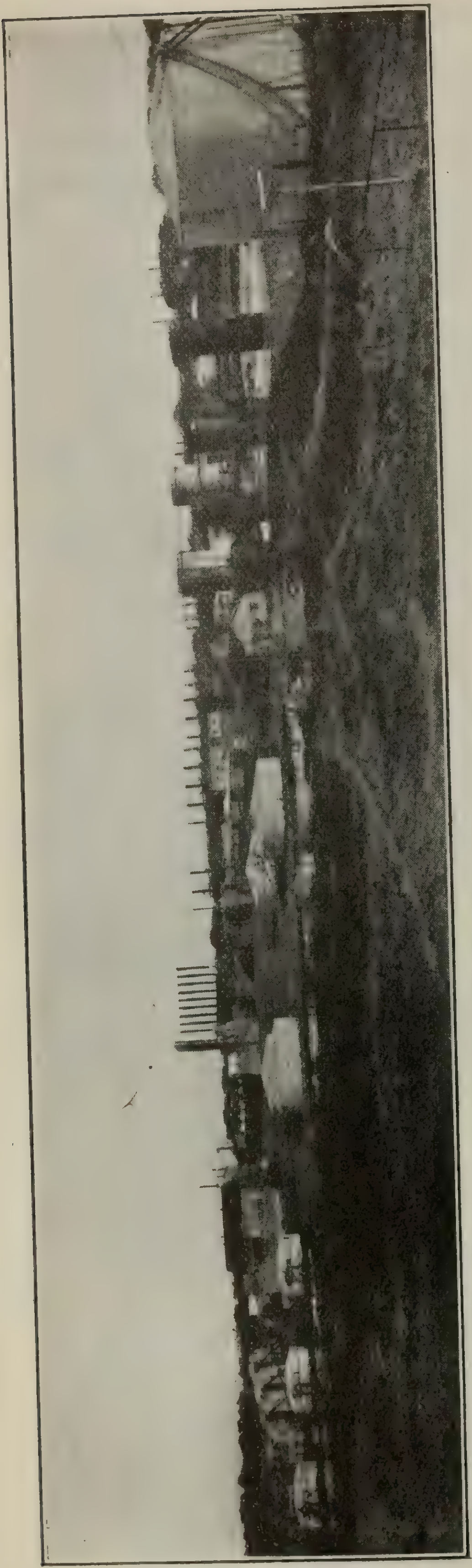
e four refineries located in Arkansas City are centrally
ed with reference to production in both Kansas and Okla-
. They also have the advantage of adequate transpor-
n facilities, the town being connected by railroad lines
the fields of Butler, Chautauqua and other counties in
as, and with those in Kay and Osage counties in Okla-
. The refineries in operation at the present time include
crude-oil refineries and one natural-gas gasoline plant.
e are the Millikan refinery, now being operated by the
Co. Oil Company, capacity, 6,000 barrels of crude oil
; the Kanotex refinery, capacity, 3,500 barrels of crude
aily; the National Oil Company refinery, capacity, 40,-
barrels of crude oil monthly; and the natural-gas gaso-
plant of the Empire Gas and Fuel Company, capacity, 60,-
00 cubic feet of gas per day, yielding 8,000 gallons of
ine.

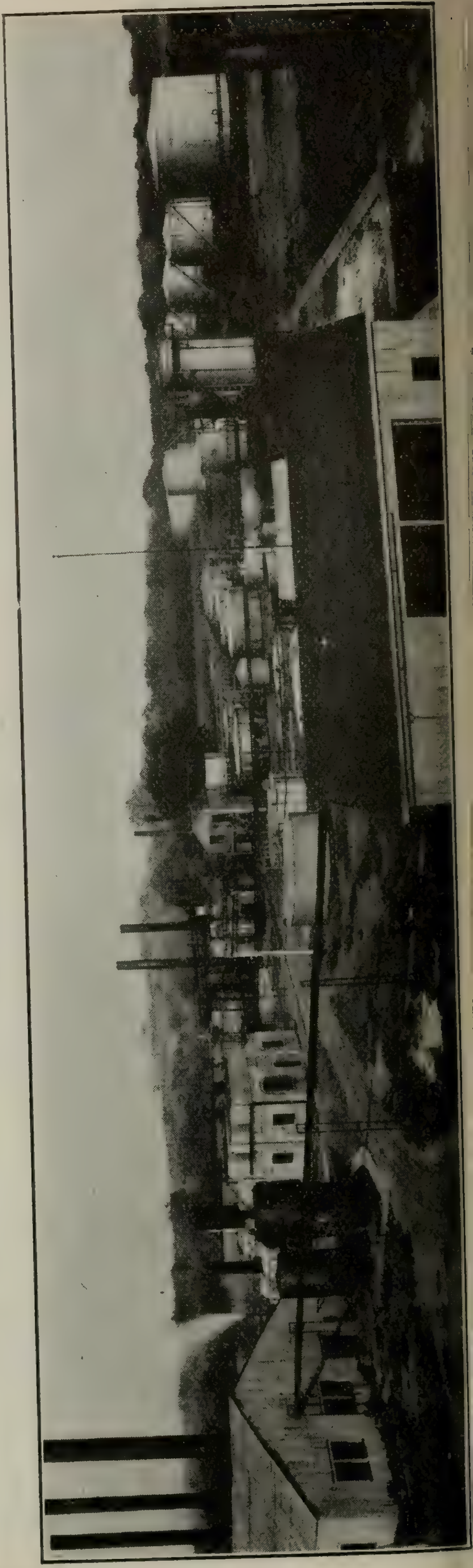
CLAY.

investigation of the clay and shale resources of the
nsas City area was made in order to locate any deposits
n might be of value in the manufacture of clay products.
les of the clay deposits which might be suitable were
under the direction of Mr. Paul Teetor, ceramic engi-
of the Geological Survey, and were sent to the ceramic
atory for testing. The final results of these tests are dis-
d in an accompanying report by Mr. Teetor.

ere is an inexhaustible supply of clay shales in the vicin-
f Arkansas City, but their possible utilization in a com-
ial way depends, of course, on a variety of factors: first
, the chemical and physical properties of the clay; next,
ocally available quantity, accessibility, amount of over-
en, etc. In the field examination, samples were taken
localities where these geographic conditions were favor-

order to make the field investigation as complete as
ble, samples were taken from all the shale members which
ar at the surface. These members are the Pearl shale,
Enterprise shale, and the Doyle shale. On account of
act that these individual geologic horizons are similar
the entire area, their physical and chemical properties





ll vary only slightly in a distance of two or three miles, and e number of samples taken is sufficient to determine the lue of all the shales appearing in the area.

ROAD MATERIALS.

Owing to the commercial opportunities and advantages of od roads to any community, the subject of road materials is vital interest to all residents of the Arkansas City district. he expense of road improvement is dependable to a large exnt on the character, abundance and accessibility of local aterials. If suitable materials are readily available in the cinity of a proposed highway, the cost of construction is reiced to a minimum, but if it is necessary to transport the aterials a great distance the cost is very materially increased.

The materials which are found in this district which are railable for road construction are limestone, sand and gravel. studying these materials, samples of all which it was ought might prove satisfactory were collected and sent to e State Road Materials Testing Laboratory at Manhattan, here tests were made to determine their physical properties.

These tests as made at the laboratory determine the specific ravity, per cent of wear, French coefficient of wear, hardness, ughness and cementation of the material submitted. In rder to meet the specifications for use in a concrete rod, stone r use in the base course should have a French coefficient of ear of not less than 5 and toughness not less than 4; and for se in the surface course, French coefficient of 8 and toughess 6.

SAMPLES.

The report on a sample of limestone collected from the W¼ of sec. 10, T. 35 S., R. 4 E., shows that this material as a French coefficient of wear of 5 and would probably give atisfactory results if used in the base course of a concrete r macadam road. This material was taken from the lower ed of the Herington limestone member. The thickness of he bed is about 2½ feet.

A sample of limestone was taken at the quarry in sec. 1, . 35 S., R. 4 E. Tests on this material show that the French oefficient is slightly below specifications, being only 4.8. This was sampled from the Fort Riley limestone member, which s about 40 feet thick. The stone varies in its physical properties, but the sample was thought to be representative of the quarry. The better grade of this material would be satisfactory for use in the base course.

A sample of the Herington limestone was collected in NW¼, sec. 7, T. 35 S., R. 4 E. This stone has a French coefficient of 4.5, slightly below specifications, but would probably give satisfaction if used in the base course. The thickness of the ledge exposed in this locality is about 5 feet.

Tests on a sample of the Winfield limestone taken in NW¼, sec. 36, T. 34 S., R. 4 E., indicate that this stone is too soft for use in road construction.

A sample was taken of the sand which is being pumped from Arkansas river east of Arkansas City by the Arkansas City Sand Company. The report from the laboratory states that this is a good, clean sand and would be satisfactory for use as fine aggregate in concrete work. It is a medium coarse sand, and the supply is practically unlimited, as a good grade of sand can probably be found at a number of places along the river.

A sample of washed gravel from the pit three miles north of Silverdale was sent to the laboratory, and their report states that this is a very hard and well-graded material which will give excellent results as road material. This gravel as taken from the pit is mixed with a red clay, and has been used locally for road building just as taken out, with good results. After a little use, the gravel with the clay binder forms a hard, comparatively impervious road bed. With a little care this type of road will give very satisfactory results.

CEMENT.

There are not at the present time any cement plants in operation in the vicinity of Arkansas City, but it is reported that a small amount of cement was manufactured several years ago from material obtained from the quarry in the Fort Riley limestone in sec. 1, T. 35 S., R. 4 E. The project was abandoned, however, before the cement had been manufactured in commercial quantities. No samples of the materials which are necessary for the production of cement—namely, limestone and shale—were taken, as the Survey is not at the present time equipped to make the necessary tests. It is probable, however, that satisfactory materials are present in this area.

BUILDING STONE.

1e most satisfactory stone for building purposes found in
Arkansas City district is the Fort Riley limestone. This
1e both to the character of the stone and the thickness of
ledge. The Fort Riley is quarried for building stone at
quarry two miles north of Silverdale. The Winfield lime-
e is too soft and porous for use as building stone. The
ngton is hard enough in some localities, but in others is
h too soft. The lower bed of the Herington has been
locally for building stone from a quarry in sec. 10, T. 35
. 4 E.

WATER SUPPLY.

1e city of Arkansas City has an abundant supply of good
er obtained from four wells located in the Arkansas river
y, the source of supply being the underflow of the river.
se wells are about 60 feet deep, and combined have a pump-
capacity of four million gallons per day. The water is prac-
ly inexhaustible, as the valley here is nearly five miles
e and the alluvial material is from 30 to 100 feet thick, thus
rding an enormous reservoir. A plentiful supply of water
be obtained at comparatively shallow depths any place
1e valleys of the Arkansas and Walnut rivers in this area.
t from the Walnut is, however, so highly mineralized on
unt of salt water and other waste products from the oil
s to the north that it cannot be used for domestic purposes.
he higher areas back from the rivers the water is obtained
n shallow wells drilled in the sedimentary rocks and from
1erous springs. Most of the area has an adequate supply
round waters at comparatively shallow depths.

hroughout the area in which the Winfield limestone is ex-
ed there are numerous springs located near the top of this
estone which furnish a good supply of water. One such
ing is located about two miles southeast of Arkansas City,
he southwest corner of sec. 5, T. 35 S., R. 4 E. Another
bout two miles northeast of town, in the NE¼, sec. 20,
4 S., R. 4 E. So far as was learned, these springs are not
ermittent, and furnish a large amount of water during the
ire year.

ight miles northwest of Arkansas City, at the little town
Geuda Springs, is situated a rather remarkable group of

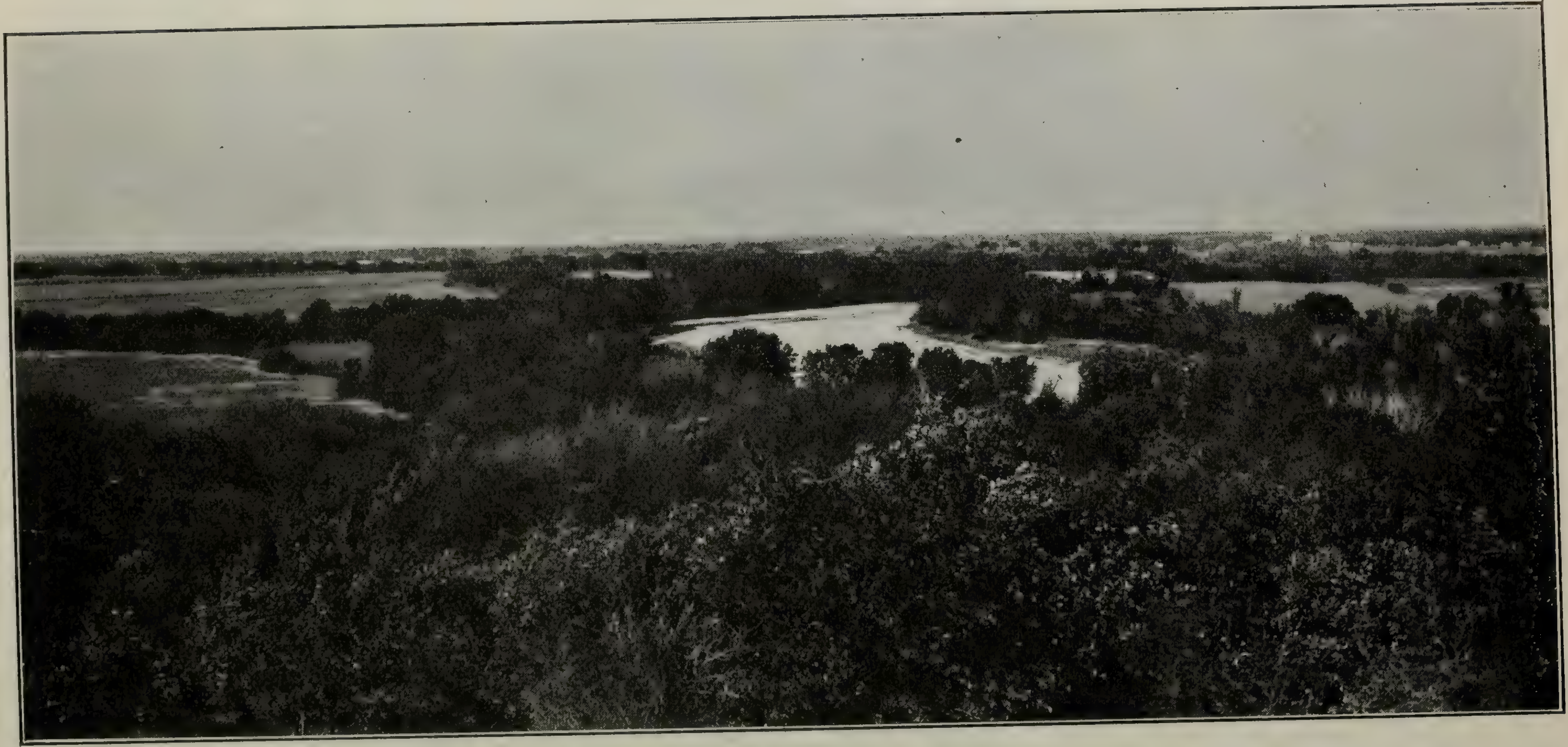


Plate XI. View of the flood plain of Arkansas river, looking west toward Arkansas City.

en springs. The water which flows from these springs is hly mineralized and is considered beneficial for medicinal rposes. As a result of the medicinal properties of this ter, Geuda Springs is more or less of a health resort, and a hotel, a bathhouse and hospital for the accommodation visitors.

Clay and Shale Resources in the Vicinity of Arkansas City, Kan.

By Paul Teetor.

INTRODUCTION.

An investigation of the clays and shales was made in connection with the work which was conducted under the coöperative arrangement made between the State Geological Survey of Kansas and the Chamber of Commerce of Arkansas City Kan.

The field work—that is, the locating and sampling of the clay and shale deposits—was done by the writer, assisted by Mr. E. R. Elledge and Mr. Lawrence Hay. The entire are around Arkansas City was thoroughly prospected and sample were taken of every deposit which had any possibility of being of commercial value.

PROPERTIES AND TESTING OF CLAYS.

The clays and shales occurring in the Arkansas City regio belong to the class which is utilized in the manufacture c structural products. These products are practically all mad by either the stiff-mud process or the dry-press process c shaping. In the former case the clays or shales are crushe and mixed with sufficient water to form a plastic mass whic can be forced through a die to produce a column of plast clay of the proper cross section. The column is then sliced int units of proper thickness. In the dry-press process the clay or shales are crushed and mixed with from 6 to 10 per cent water, and the moist, finely divided material is fed into a met die box and sufficient pressure exerted upon the top and botto of the die to compress the clay into a mass of sufficient streng to withstand the ordinary handling in the process of manufa ture. For this second type of clay the following tests are importance in determining the commercial value of the d posits.

The working properties of the plastic mass, after the prop amount of water has been added to produce best worki operties, are of prime importance. If the clay is not plastic ough the clay column will not hold together as it issues from e die; if too plastic it will develop laminations while being aped, and is also very likely to crack while drying.

The percentage of drying shrinkage is also of importance, cause a clay with a high drying shrinkage is very apt to ack during drying.

The properties of the clay after it has been burned at differ- t temperatures are of prime importance, the three most im- rtant properties being color, burning shrinkage, and porosity. om the burning shrinkage can be estimated the warping and acking which can be expected during burning. The porosity ves an estimate of the strength and also of the range of nperature in which the clay can be properly matured in the n. By porosity is meant the pore space present in the rned specimen, and this is determined by dividing the weight water absorbed by the specimen while submerged in water der a vacuum, by the volume of the piece.

It is also a well-known fact that the presence of limestone rticles, coarser than 30-mesh, in a clay render it useless for e manufacture of structural clay products, owing to the fact at during the firing of the clay the limestone is converted to ie. Upon exposure to the atmosphere the lime absorbs water d is converted into lime hydrate, with an increase in volume d a resulting pressure on the surrounding clay particles suffi- nt to cause a rupture known as a "popped brick."

ARKANSAS CITY CLAYS.

There are a number of shales in the Arkansas City area. me are soft shales containing limestone concretions and are sy to cut with a pick and shovel, while others are very hard d might be termed shaly limestone. In each case a ten- und sample was secured by cutting away the weathered face the outcrop and taking the sample so as to represent the ire depth of the exposed deposit. These samples were sent the ceramic laboratory of the State Geological Survey for ailed testing to determine the commercial value of the rious deposits. There were in all eight deposits of shale ich appeared worthy of tests. A description of these de- its and the results of the tests follow.

PEARL SHALE.

Sample No. 505 represents a typical deposit of the Pearl shale located in the southeast corner of sec. 21, T. 34 S., R. 3 E., three miles from Arkansas City and three-fourths mile from the railroad. It has a thickness of 10 to 12 feet, is 500 feet long (estimated), and is probably 300 to 400 feet wide. There is an overburden of 15 to 20 feet, which contains limestone. This overburden is so thick compared to the thickness of the deposit itself, that it could be removed only at a cost prohibitive, under normal conditions, to the manufacture of structural material such as brick and tile. It is therefore probable that this deposit is of no commercial value.

This clay has poor working properties as regards its fitness for working by the stiff-mud process, even when ground to pass the 10-mesh sieve, although when passed through a 20-mesh sieve its working properties are slightly better. It should work best by the dry-press method of shaping. Its water of plasticity is 19.8 per cent and its drying shrinkage 4.83 per cent. The clay, after being ground and mixed with water to produce the best working properties, was molded by hand into briquettes. These were dried and the drying shrinkage obtained. They were then placed in a kiln for the purpose of determining the properties of the clay at higher temperatures. Pieces were drawn from the kiln at temperatures of Seger cones listed below, the approximate equivalents in the Fahrenheit scale as reported by the manufacturers being also given:

Cone 010	174½° F.
Cone 07	1,850° F.
Cone 05	1,922° F.
Cone 02	2,030° F.
Cone 1	2,102° F.
Cone 3	2,174° F.
Cone 5	2,246° F.
Cone 7	2,318° F.

The final specimens were examined for burning shrinkag porosity, color, and hardness. These data are given in table

Sample No. 505, when ground to pass a 10-mesh sieve coarser, produces a brick of dark-brown color and one th disintegrates rapidly when exposed to the weather. This due to the formation of lime hydrate from free lime particl which are present. When ground to pass a 20-mesh sieve produces a sound brick at cone 4, with a beautiful brown colo

Table No. 1.

ple o.		Temperature.							
		Cone 010.	Cone 07.	Cone 05.	Cone 02.	Cone 1.	Cone 3.	Cone 5.	Cone 7.
05	Burning shrinkage, per cent....	....	0.69	1.60	1.60	2.12	3.19	2.29	28.96
	Porosity, per cent....	....	45.94	43.90	43.98	39.50	38.70	20.33	68.02
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.
	Color........	Grey brown.	Light brown.	Light brown.	Light brown.	Brown.	Brown.	Brown.	Brown.
06	Burning shrinkage, per cent....	-3.33	-3.33	-3.33	-3.33	-4.03	-2.67	0.89	7.64
	Porosity, per cent....	56.50	55.30	55.30	55.42	54.82	54.17	44.97	29.45
	Hardness.....	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.
	Color........	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Cream.	Cream.	Cream.
07	Burning shrinkage, per cent....	-2.27	-1.34	-2.24	-2.02	....	3.18	1.80	-2.02
	Porosity, per cent....	63.75	61.31	62.82	62.78	62.91	63.14	61.82	62.56
	Hardness.....	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.
	Color........	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.
08	Burning shrinkage, per cent....	1.87	3.26	3.96	2.13	2.82	6.66	Melted.	Melted.
	Porosity, per cent....	25.61	25.31	21.30	22.06	15.43	4.05	....	....
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....	....
	Color........	Light red.	Light red.	Red.	Red.	Red.	Red.	....	....
09	Burning shrinkage, per cent....	2.92	5.46	6.12	6.35	6.13	6.36	Melted.	Melted.
	Porosity, per cent....	23.72	22.13	19.58	16.81	13.01	3.62	....	....
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....	....
	Color........	Brown.	Brown.	Brown.	Brown.	Brown.	Brown.	....	....

Table No. 1—Concluded.

Sample No.		Temperature.							
		Cone 010.	Cone 07.	Cone 05.	Cone 02.	Cone 1.	Cone 3.	Cone 5.	Cone 7.
510	Burning shrinkage, per cent....	-1.17	....	0.70	1.88	0.93	1.40	4.94	....
	Porosity, per cent....	43.11	....	45.05	44.51	43.77	43.48	33.49	....
	Hardness.....	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	Softer than steel.	....
	Color........	Light cream.	Light cream.	Light cream.	Light cream.	Light cream.	Cream.	Cream.	....
511	Burning shrinkage, per cent....	0.71	0.71	....	2.13	1.90	0.69	6.99	....
	Porosity, per cent....	44.58	45.27	46.60	36.10	25.27	31.70	2.11	....
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....
	Color........	Dark gray.	Dark gray.	Greenish gray.	Greenish gray.	Greenish gray.	Green-yellow.	Mustard.	....
512	Burning shrinkage, per cent....	0.95	1.41	1.63	2.34	5.15	6.55	5.15	....
	Porosity, per cent....	26.16	....	26.39	25.57	13.93	8.35	1.85	....
	Hardness.....	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	Harder than steel.	....
	Color........	Light red.	Light red.	Red.	Red.	Red.	Dark red.	Dark red.	

To obtain this degree of fineness in commercial manufacture, however, would require the installation of special grinding equipment. The maturing range of the clay is also very short. Therefore, while making a satisfactory brick under certain conditions, this clay is not a promising one from a commercial standpoint.

ENTERPRISE SHALE.

Sample No. 506 represents a deposit of clay which is a part of the Enterprise member, located in the northeast corner of the NE¼ NW¼, sec. 7, T. 34 S., R. 4 E. This deposit is 9 feet thick, 300 feet long (estimated), and 150 feet wide. It carries a 6-inch ledge of limestone in the center and has 6 to 8 feet of overburden. The exposure from which the sample was taken is three miles from Arkansas City, one-fourth mile from a railroad, and one-fourth mile from the interurban rail-

d. This clay was tested by the same method as described
No. 505. It has very poor working properties in the plastic
:e and could not be worked by stiff-mud methods. Its
:er of plasticity is 20.61 per cent; drying shrinkage is 2.71
cent. The properties of the fired specimens are given in
le 1. It is interesting to note that this clay, upon being
d, expands instead of shrinking. It contains a high per-
tage of limestone in a fine state of subdivision. The poor
·king properties and the softness of the fired material ren-
this clay unfit for the manufacture of structural clay prod-
s.

ample No. 507 represents another part of the Enterprise
le located in the northeast corner of the NW¼, sec. 35,
33 S., R. 4 E., 8½ miles from Arkansas City, 4 miles from
railroad, and 4 miles from the interurban. It is so similar
No. 506 that the same statements hold true for both clays.
available clay at this locality is 40 feet thick, 1,000 feet
e, and covered with a 3-foot ledge of limestone.

ample No. 509 was collected from the Enterprise shale lo-
ed in the SW¼ NE¼, sec. 18, T. 34 S., R. 4 E. The work-
deposit here is 18 feet thick, 500 feet wide, and 500 feet
(estimated), and is covered with 15 feet of limestone.
en ground and mixed with water to produce maximum
·king qualities it is found that 18.17 per cent water is re-
red. The working properties are very poor and it would
be possible to work the clay by modern stiff-mud methods.
drying shrinkage is 3.83 per cent. The properties of the
cimen when fired at different temperatures are given in
le 1. This shale contains a large amount of coarse lime-
ne which renders it practically useless, because when
ned at a low temperature it will disintegrate upon ex-
ure to the weather, and at higher temperatures it softens
of shape.

ample No. 510 represents a deposit of the same shale out-
pping in the NE¼ SW¼, sec. 18, T. 34 S., R. 4 E., on the
thwest side of the same hill in which sample No. 509 oc-
s. The water of plasticity of this clay is 20.88 per cent.
drying shrinkage is 6.55 per cent. This clay, unlike sam-
No. 509, has very good working properties in the plastic
dition. When fired in a kiln, however, it is found that
material does not develop sufficient strength and hardness

to be of value for the manufacture of brick and tile. It also contains limestone particles of sufficient size to cause disintegration of the bricks after they come from the kiln. The properties of the fired specimen are given in table 1.

Sample No. 511 was also collected from a deposit of the En-

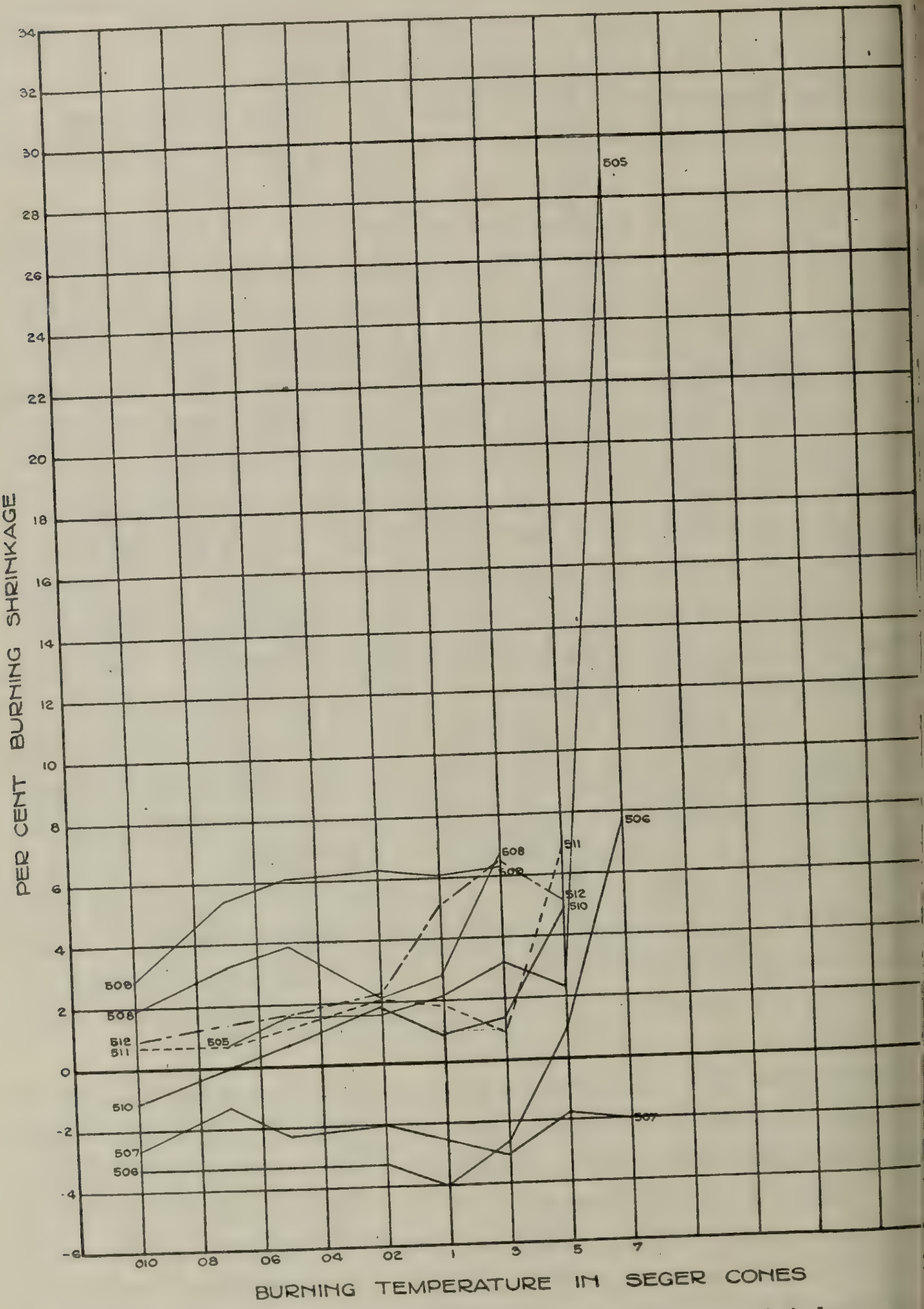


PLATE XII. Burning shrinkage-temperature curves of Arkansas City clays.

prise shale in the northwest corner of the SW¼, sec. 3, T. S., R. 4 E., 4½ miles from Arkansas City, 3 miles from the lroad, and 4½ miles from the interurban railroad. The ilable deposit is at least 6 feet thick, 300 feet wide and 500 t long (estimated), and with little or no overburden. It uired 20.19 per cent water to develop best plasticity. It very good working properties and can be easily shaped in stiff-mud condition. The drying shrinkage is 9.33 per t. The properties of the burned test pieces are given in le 1. When fired at a temperature of cone 05 or lower, the ces disintegrate owing to the coarse particles of limestone sent. At cone 4 it has softened sufficiently to cause the ces to stick together. This gives it a narrow maturing ge. Therefore, it is not a good clay from a commercial wpoint. Further tests might develop the fact that it could utilized for the manufacture of a yellowish buff-colored face ck.

DOYLE SHALE.

Sample No. 508 represents a deposit of the Doyle shale lo-ed in the southeast corner of the SW¼, sec. 35, T. 33 S., R. E., which is 7½ miles from the interurban railroad. It is a xture of red, green and yellow clays located on top of lime-ne, and is 8 to 10 feet thick, 300 feet wide, and 500 feet long stimated). The overburden consists of limestone and varies thickness from a few inches to 15 feet. This clay when ound and properly mixed with water has very good working operties and could be worked by any of the methods in mmon use for the manufacture of such products as brick, e, etc. Its water of plasticity, or the amount of water neces-ry to add to produce the best working properties, is 22.25 r cent of its dry weight. The drying shrinkage is 7.06 per nt. The clay also has very good burning properties as re-rds shrinkage, porosity, color and hardness. It needs to be rned at a temperature not below that of cone 05, but cone 1 ould be a more suitable temperature, as it would produce a oduct of better color and strength. Data for the burned clay e given in table I. The briquettes made from this clay, after ing fired to the best maturing temperatures, slowly disinte-rate, due to the presence of lime particles. This deposit is, erefore, of no commercial value.

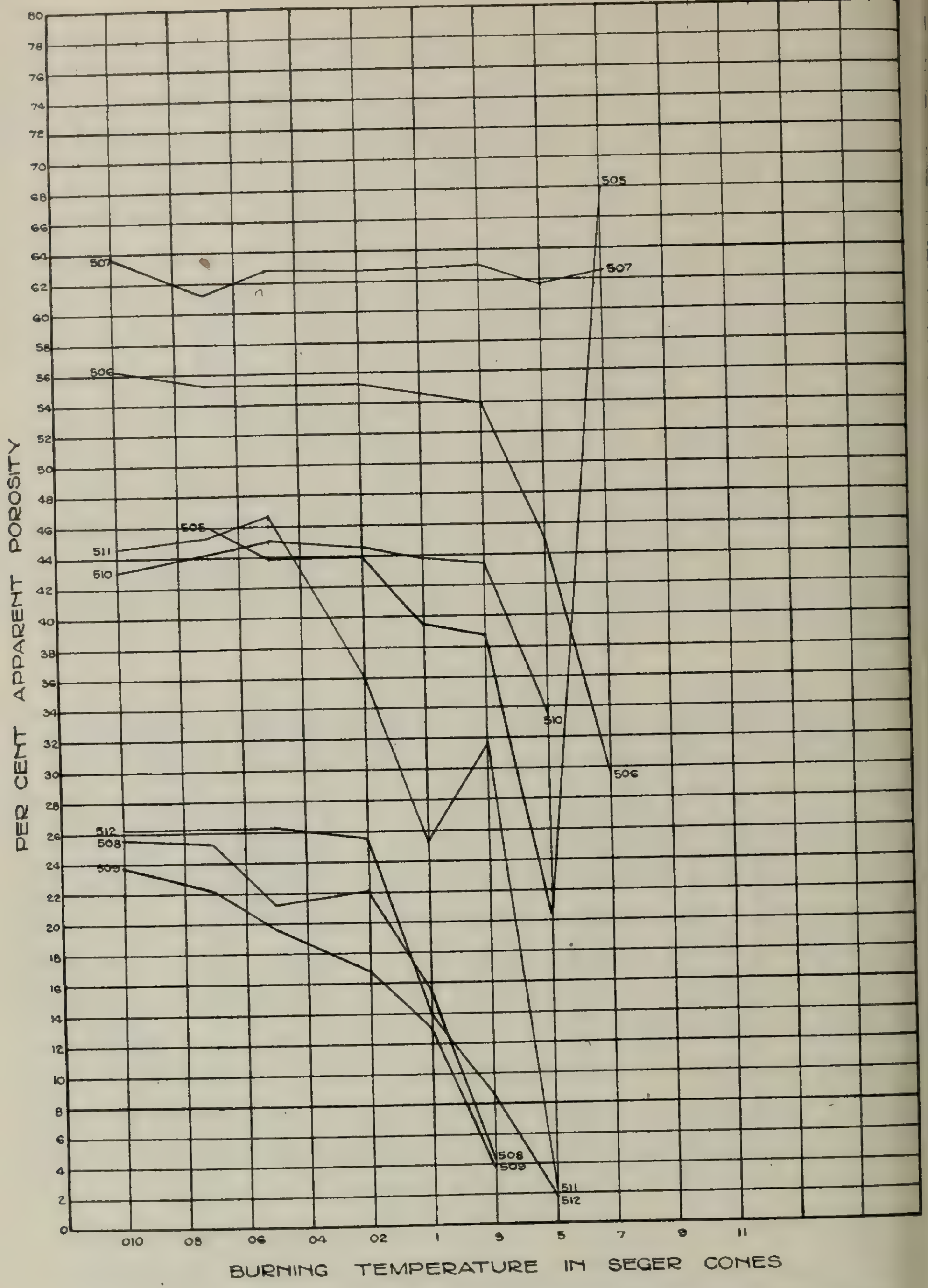


PLATE XIII. Porosity-temperature curves of Arkansas City clays.

Sample No. 512 was also taken from a deposit of the Doyl shale located in the northwest corner of the NW¼, sec. 17 R. 34 S., R. 4 E. It is one mile from the interurban railroa and about one-half mile from the Santa Fe. The exposed portion is 5 feet thick and 150 feet wide. The overburden is fron 4 to 10 feet thick. The water of plasticity is 21.38 per cent

ying shrinkage is 6.55 per cent. When ground and mixed
th water it has good working properties and good plas-
ity, and can be shaped by the stiff-mud process now in com-
n use. The properties of the burned specimens are given
table 1. When fired, the clay disintegrates when exposed
the atmosphere. At cone 5 it has softened sufficiently to
se slight sticking. It develops a good red color, with an
asional yellow spot due to lime particles. This clay could
utilized for the manufacture of brick and tile in so far as
color of the clay is concerned, but on account of the lime
ich is contained, is of little commercial value.

t is of interest to note that the samples collected from the
yle shale member, Nos. 508 and 512, are by far the best
ys tested and practically the only ones possessing proper-
s approaching commercial value. It would appear that the
st promising field for future prospecting would be for out-
ps of the Doyle shale member. The burning shrinkage-
nperature relations of these clays are graphically shown in
te XII. The porosity-temperature relations are shown in
te XIII. These curves are self-explanatory.

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STATE GEOLOGICAL SURVEY *of* KANSAS

RAYMOND C. MOORE, State Geologist

BULLETIN 10

PART I

THE GEOLOGY OF RUSSELL COUNTY, KANSAS

With Special Reference to Oil and Gas Resources

By W. W. RUBEY and N. W. BASS

PART II

A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas

By M. N. BRAMLETTE

PART III

Fossils from Wells in Central Kansas

By RAYMOND C. MOORE

Prepared in coöperation with
The United States Geological Survey

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PRINTED BY KANSAS STATE PRINTING PLANT
B. P. WALKER, STATE PRINTER
TOPEKA 1925
10-6048

Publications of the State Geological Survey are distributed from Lawrence, Kansas.

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STATE GEOLOGICAL SURVEY OF KANSAS.

Ernest H. Lindley, Ph.D.,
Chancellor of the University of Kansas, and
ex officio Director of the Survey.
Raymond C. Moore, Ph.D.,
State Geologist.

CONTENTS.

PAGE

ART I.—THE GEOLOGY OF RUSSELL COUNTY, KANSAS, WITH SPECIAL REFERENCE TO OIL AND GAS RESOURCES 7

By W. W. RUBEY and N. W. BASS.

- Introduction 7
  - Significance of the investigation in Russell county (by *Raymond C. Moore*) 7
  - Methods of field work 10
  - Acknowledgments 10
  - Geography and topography 11
  - History of oil and gas production 13
  - Character of the oil 14
- Rocks exposed 15
  - Cenozoic 18
    - Recent 18
      - Alluvium, soil and talus material 18
      - Lower terrace deposits 18
      - Dune sand (?) 19
    - Pleistocene 19
      - Gravel deposits of Saline and Smoky Hill rivers 19
        - Subdivisions of the gravels 19
        - Lower gravel beds on Saline river 19
        - Upper gravel beds on Saline river 19
        - Gravel beds near Smoky Hill river 19
        - Volcanic ash 20
      - Fossils 20
      - Age and correlation 21
    - Tertiary (?) 23
      - High terrace gravels (*Ogallala? formation) 23
    - Uselessness of Cenozoic rocks for structural mapping 25
  - Mesozoic 25
    - Cretaceous 25
      - Niobrara formation 25
        - Smoky Hill chalk member 26
          - Character and distribution 26
          - Fossils 27
          - Means of recognition 27
          - Difficulty of mapping 28
          - Name 28
        - Fort Hays limestone member 28
          - Character and distribution 28
          - Fossils 30
          - Topographic prominence 30
          - Means of recognition 30
          - Unreliability of the Fort Hays member for detailed mapping 31
          - Name 32

---

* In scientific usage, as a geological term, the accepted spelling of this word is "Ogalalla." e spelling used in this bulletin, however, is in conformity to Webster's New International ctionary.

PAGE

Rocks exposed—Mesozoic—Cretaceous—*Continued.*
- The term Benton.... 32
- Carlile shale.... 32
  - Blue Hill shale member.... 33
    - Upper sandstone divisicn.... 33
    - Lower shale and concretion division.... 34
    - Fossils.... 36
    - Topographic expression.... 36
    - Soil and vegetation.... 37
    - Means of recognition.... 37
    - Horizons suitable for mapping.... 37
    - Name.... 39
  - Fairport chalky shale member.... 40
    - Character and distribution.... 40
    - Distinctive beds.... 41
    - Fossils.... 42
    - Means of recognition.... 4
    - Beds useful in detailed mapping.... 44
    - Name and correlation.... 44
- Greenhorn limestone.... 4
  - Upper member.... 4
  - Jetmore chalk member.... 4
  - Unnamed member.... 4
  - Lincoln limestone member.... 4
  - Distinctive colors of the members.... 4
  - Fossils.... 4
  - Topographic expression.... 4
  - Soil and vegetation.... 4
  - Resemblance to other Cretaceous strata.... 4
  - Value for detailed mapping.... 5
  - Names of members.... 5
- Graneros shale.... 5
  - Lithology.... 5
  - Fossils....
  - Exposures....
  - Distinguishing features....
  - Unsuitability for mapping....
  - Name and correlation....
- Dakota sandstone....
  - Evenly bedded strata....
    - Upper sandstone unit....
    - Lignitic beds....
    - Clay shale beds....
    - Variegated mudstone unit....
  - Rocktown channel sandstone member....
    - Lithology....
    - Distribution of the sandstone lenses....
    - Name....

Rocks exposed—Mesozoic—Cretaceous—*Concluded.*
Dakota sandstone—*Concluded.*

PAGE
- Origin 62
- Fossils in the Dakota sandstone 62
- Varying prominence 63
- Similarity to other strata 64
- Uselessness of the Dakota sandstone for mapping of structure 64

Rocks concealed 65
Structure 66
- Surface rocks 66
  - Structural contour map of the top of the Greenhorn limestone . . 66
  - Prominent north-trending anticlines 67
  - The Fairport-Natoma anticline 67
  - Lesser folds 68
  - Faults 68
- Attitude of rocks not exposed 69
  - Thinning of shallower rock units northeastward 69
  - Map of the elevations of the base of the salt series 71
  - Increasing steepness of dip with depth below surface 71
- Origin (by *W. W. Rubey*) 72
  - Conformity of strata to the shape of buried land forms 73
  - Effect of buried lenses of sandstone 74
  - Structure in surface rocks formed by movement along deep-seated faults 75
  - Folds formed by leaching of salt beds 79
  - Application of principles to structure of Russell county 80
    - Gentle unsystematic folds 80
    - Prominent north-trending anticlines 81
    - Probable origin of structure of Russell county 84
  - Economic significance of method of origin 85

RT II.—A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas 87
By M. N. Bramlette.

RT III.—Fossils from Wells in Central Kansas 91
By Raymond C. Moore.

ILLUSTRATIONS.

PAGE

PLATE
I. Reconnaissance geologic map of Russell county, Kansas. . . . . . *(*In pocket*)
II. A. Idealized profile through the Cretaceous strata of Russell county, Kansas. . . . . (*In pocket*)
B. Generalized columnar section of the rocks exposed in Russell county, Kansas. . . . . (*In pocket*)
III. Approximate location in the Dakota area of Russell county of meander belt of stream and tributaries (?) that deposited the Rocktown channel sandstone member of the Dakota sandstone. . . . . . (*In pocket*)
IV. Generalized structural contour map of Russell county, Kansas, (*In pocket*)
V. Attitude of base of salt series of Wellington formation in Russell and adjacent counties. 70
VI. Correlation of well records, showing tentative determinations of geologic units extending from Marion county into Russell county, (*In pocket*)
VII. Graphic comparison between the drillers' records and the cuttings from five of the wells. . . . . (*In pocket*)

FIGURE
1. Index map showing location of Russell county 11
2. High terrace gravels (Ogallala? formation) in sec. 18, T. 13 S., R. 15 W., Russell county 23
3. A concretion in the lower part of the Fairport member of the Carlile shale. 24
4. A prominent bench capped by ironstone concretions in basal part of the Blue Hill shale member of the Carlile shale. 38
5. Slabs of chalky limestone of the Jetmore member of the Greenhorn limestone, shown as they typically cover the surface in areas of rather poor exposures 38
6. Contact of the Graneros shale and Dakota sandstone. 55
7. Evenly bedded sandstone at the top of the Dakota formation, underlain by variegated shale. 55
8. Interfingering of Rocktown channel sandstone member and variegated shale in the Dakota sandstone. 58
9. Local unconformity of the Rocktown channel sandstone member on shale beds in the Dakota sandstone. 58
10. Sandstone "hoodoos" in Rocktown. 60
11. A sandstone "hoodoo" in Rocktown. A weathered block of the Rocktown channel sandstone member in sec. 4, T. 13 S., R. 11 W., showing oblique laminæ dipping westward. 6

Table of rock formations in Russell county, Kansas 1
Mesozoic fossils identified by J. B. Reeside, Jr. . . . . (*In pocket*

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* The large plates included in this bulletin will be found in a pocket on the inside of th back cover.

PART I.

he Geology of Russell County, Kansas, With Special Reference to Oil and Gas Resources.

By W. W. Rubey and N. W. Bass.

INTRODUCTION.

Significance of the Investigation in Russell County.[1]

AFTER the richly productive oil and gas fields in eastern Kansas and Oklahoma had been discovered and developed, the oil-roducing territory in this region was gradually and rather slowly xtended westward to areas where the formations that contain oil the region to the east are more deeply buried. This westward ovement of the border of Mid-Continent production has not been mply progressive, for much country that had been partly explored ithout success was passed over in going from the fields of Wilson nd Allen counties to the test wells in Butler county, the success f which marked the beginning of the chief "oil age" in Kansas. he discovery wells in the highly productive fields of Butler and arion counties were located by means of good geologic evidence, nd the development of these fields has been guided mainly by eologic studies.[2]

The development of oil and gas in central and western Kansas est of Butler county has met many obstacles. The beds of lime-one in the oil fields of Butler and Marion counties, which furnished ready and satisfactory means of determining the geologic structure, re practically the uppermost hard rocks in the Paleozoic system in ansas. In central Kansas the soft, variously colored shales, the asily soluble beds of salt, and the irregular, mainly rather weak Red Beds," which here constitute the uppermost Paleozoic strata, re very poorly exposed, or in wide areas are not exposed at all. ost of central Kansas lacks beds that can be traced over territory rge enough to make them valuable as key horizons in mapping he geologic structure. Consequently there is very little to guide exploration for oil and gas. Though a considerable number of wells have been drilled in this region, mostly on a "hit or miss" plan, only one or two have been productive. Some of the larger oil companies have recently been determining the geologic structure of parts of this region by drilling shallow diamond-drill test wells down to one of the beds of limestone that lies near the surface and that may be used as a datum plane.

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[1] By Raymond C. Moore.

[2] The El Dorado oil field, by A. E. Fath: Kansas Geol. Survey Bull. 7, 1920.

Next to the belt that lacks surface key beds lie the basal deposits, mainly sandstone, of the Cretaceous system. These rocks, which crop out in a belt thirty to forty miles wide, are millions of years younger than the next underlying series of rocks, and between the time of the deposition of the two series there intervened a long period in which the underlying rocks were exposed and more or less eroded. The sandstones of the Cretaceous system, therefore, rest at some places on higher and at others on lower beds in the underlying series. The erosion at the close of Paleozoic sedimentation in this region has produced a lack of parallelism of the beds, and at some places, doubtless, has made the relations between the younger and older rock series very irregular. Further, the belt of sandstone at the base of the Cretaceous is extremely irregular. It shows abundant cross-bedding, and affords, so far as known, no horizon that can be followed with confidence in structural mapping. The exposures in parts of the belt where this zone is nearest the surface are very poor. Thus there is a fairly wide belt west of the oil fields in Butler and Marion counties in which, though it may contain beds that will yield oil or gas, the surface affords no evidence that is of use to the geologist in guiding exploration.

Above the Dakota sandstone, and therefore appearing at the surface in a belt that extends across the state next west of and parallel to the outcrops of the sandstone, there is a series of alternating beds of dark shale and thin, more or less resistent chalky limestone. In previous publications this division of the Cretaceous system has been called the Benton, but in this report it is divided into three formations—the Graneros shale below, the Greenhorn limestone in the middle, and the Carlile shale above. Each of these formations contains horizons that can be traced more or less easily and that can be used in determining the structure of the Cretaceous rocks.

The information concerning structure that is afforded by exposures of the Greenhorn limestone has led to the discovery, in the northwestern part of Russell county, of a long, well-defined fold,

ıich offered favorable conditions for the accumulation of oil or
.s and on which a test well was drilled late in 1923. The pre-
ninary geologic work in this area was done by Mr. V. H. McNutt,
ıd the well was drilled by the M. M. Valerius Oil and Gas Com-
.ny, whose president, Mr. Valerius, is also a geologist. The dis-
very of oil in commercial quantities by means of this test well is
great importance, not simply because of the additional oil that
ll be obtained from this new field, now more definitely indicated
other large producers, but because of its significance as to the
ssibility of obtaining oil in other parts of the Great Plains country
western Kansas.

Because of the importance of the new oil production in Russell
unty and the widespread interest in it, the State Geological Survey
ıdertook to make field examinations in this and other parts of
estern Kansas in order to gather information that may aid in ex-
nding the area of this production. The geologic mapping done by
e geologists of the oil companies has been confined essentially to
eas where the Greenhorn limestone is exposed. In the course of
ese examinations several large questions arose: To what extent
n the Graneros and Carlile shales be used in determining geologic
ucture? Can the surface structure be reliably ascertained in the
ick Niobrara chalk, which covers large areas farther west? What
the producing formation in the Russell county field, and what are
e prospects of production from greater depths? What is the struc-
re of the rocks below the surface, especially at the producing hori-
n? Is there any indication as to the source of oil; that is, as to
e "mother beds" in which the oil originated? What is the form
character of the particular fold on which oil and gas have been
und here, and what bearing has it on other drilling in western
ansas? What probably produced the fold? How do the answers
these questions affect the prospects of obtaining oil in other parts
western Kansas?

The State Survey, unable with its present resources to undertake
is investigation, turned to the United States Geological Survey for
d, and made arrangements for a coöperative study of the develop-
ent of oil and gas in Kansas. A survey of the area in Russell
unty was first planned, and to this work Messrs. W. W. Rubey
ıd N. W. Bass were assigned. At the same time Mr. M. N. Bram-
tte undertook a microscopic study of all available drill cuttings
om deep wells in eastern, central and western Kansas, and, supple-
enting the information thus obtained with well records, endeavored

to trace westward to Russell county the geologic divisions found in the eastern part of the state. After they had examined Russell county, Mr. Rubey and Mr. Bramlette were transferred to work outside of Kansas, but studies of oil and gas in the state are being continued by Mr. Bass, and the state geologist.

METHODS OF FIELD WORK.

The work in Russell county on which this report is based was done between March and June, 1924. A brief reconnaissance of the formations exposed in eastern, central and southern Kansas was made at the beginning of the work by Raymond C. Moore, state geologist of Kansas; K. C. Heald, of the United States Geological Survey, and M. N. Bramlette, who was to make a special study of the subsurface geology and the correlation of the underground formations in Russell county. The field work in Russell county was done by W. W. Rubey and N. W. Bass.

Numerous sections of the outcropping rocks were examined and measured by Locke level or stadia, and the position of the outcropping formations throughout the county was sketched on the United States Geological Survey's topographic base maps of the region, which in all but a few very small areas were found to be sufficiently accurate for this purpose. Each drilling well was visited several times to collect records and samples of the formations drilled through.

ACKNOWLEDGMENTS.

In collecting cuttings from the wells, in granting permission to inspect detailed structural maps, and in other ways assistance was generously given by M. M. Valerius, the Stearns-Streeter Drilling Company, Sidney Powers; E. A. Hall, of the Midwest Oil and Refining Company; H. L. Baldwin, of the Mississippi Valley Oil Company; E. R. Lloyd, H. E. Munson, J. L. Gallagher, V. H. McNutt, C. T. Lupton, and all the drillers in the field. The writers are deeply indebted to J. B. Reeside, Jr., of the United States Geological Survey, who spent several days in field conference with them, identifying fossils and determining the limits of the stratigraphic units. Thanks are also due J. L. Phinney, of Russell, who kindly guided the writers to a fossiliferous outcrop of Cenozoic deposits and donated to the State Museum an elephant tooth found there years before.

Geography and Topography.

Russell county, which is about thirty miles square, lies slightly orthwest of the center of Kansas, near the eastern border of the reat Plains region. More than half a dozen towns, of which Rusell, the county seat and headquarters of the new oil field, is the rgest, stand along the two lines of the Union Pacific railroad that un through the county. Two other towns, Fairport and Milberger, re far from the railroad. The chief occupation of the residents of ussell county is agriculture, and the principal crop raised is wheat. he wagon and automobile roads throughout the county are well ept.

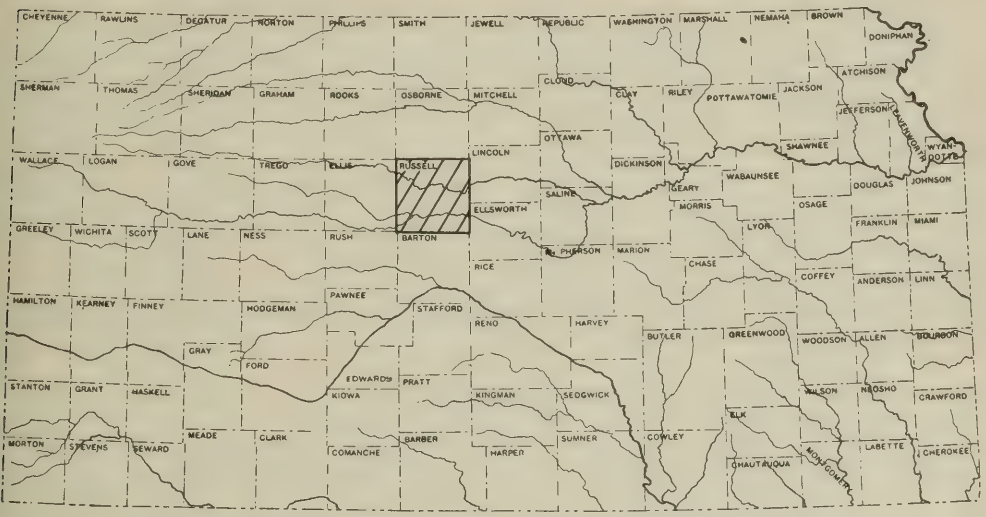

Fig. 1. Index map showing location of Russell county.

The highest point above sea level in Russell county, found on the igh ridges in its northwest corner, has an elevation of about 2,050 eet, and the lowest point, where Saline river leaves the county, ear the middle of its eastern boundary, has an elevation of about ,430 feet. The uplands slope northeastward from above 2,000 feet n the northwest corner to 1,700 feet above sea level near the northast corner of the county. Two rivers, the Saline and Smoky Hill, nd Wolf creek, a large tributary of Saline river, flow eastward cross Russell county. The other tributaries, several of which have arge valleys, flow northeastward and southeastward into the main treams. Saline river falls about 265 feet in a straight-line distance f 32 miles across the county—a gradient of over 8 feet to the mile. The bed of Smoky Hill river is 200 feet lower at the eastern border f the county than at the western, where it is about 1,770 feet above sea level—a fall of less than 6½ feet to the mile. The relief along Saline river is 250 to 300 feet and that along Smoky Hill river is 150 feet or less, but the uplands are featureless and nearly flat.

The undissected uplands form nearly half the surface of the county, the steep to gentle slopes into the valleys make up most of the remainder, and the flat valleys comprise about a fifth.

The form of the treeless upland is controlled largely by the structure and the lithology of the surface rocks, the moderately resistant chalk beds of the Greenhorn and Carlile formations upholding it in all but the northwest corner of the county, where the higher Blue Hills scarp and plateau is made by chalk beds in the Niobrara formation.

The northern margins of the uplands between the larger streams terminate abruptly in steep slopes that lead down to the valleys, but the southern margins merge by gentle slopes into the valleys. This difference is noticeable even along the smaller tributary streams and on the valleys the trend of which inclines even less than 45° from north. The greater steepness of the northward-facing slopes is a characteristic feature of the topography of western Kansas. To one unacquainted with the region it suggests broken scarps at the north and dip slopes to the south, but the regional dip in central Kansas is northward.

The larger valleys are from less than one to several miles wide and their floors slope gently on the north sides, but commonly rise abruptly from the south sides. Of the tributaries from the south only the larger ones have noticeably flattened valley floors. The banks of the streams are commonly wooded. The capture of the headwaters of minor tributaries of Smoky Hill river by northward-flowing tributaries of Saline river is approaching, especially near the eastern border of the county.

Many of the spurs between the tributary streams are long and narrow, and those that run northward from the larger divides are steep-sided, prominently benched by beds of harder rock, and in places made irregular by small, isolated remnants of a higher, harder bed. These spurs are closely controlled by lithology, most of them being capped by one hard chalk bed of the Greenhorn limestone. The outcrops of rock in Russell county are essentially restricted to the valley walls and are generally best exposed in the northward-facing bluffs.

HISTORY OF OIL AND GAS PRODUCTION.

In Russell county, as in many areas in western Kansas, there was onsiderable activity in leasing oil and gas as early as 1917, but no rilling was done until July, 1923, when the M. M. Valerius Oil and as Company, of Tulsa, Okla., "spudded in" a well in the southwest orner of the SE¼ of sec. 8, T. 12 S., R. 15 W., that was destined to pen a new oil pool more than a hundred miles from the nearest ommercial producing field. The well was drilled on the C. C. swald farm, on land leased from the Lucky Seven Oil Company, local company holding leases on an area comprising nearly three-urths of a township in the vicinity of the present Russell pool. everal encouraging shows of gas and oil were struck late in the ll. Late in November oil was produced at the rate of about 10 arrels a day, and early in December the sand now producing was ruck at a depth of 2,998 feet. Drilling was continued to the epth of 3,037 feet, but the well was not shot. A pipe line was id to connect the well with tank cars at Paradise, on the Union acific railroad. The output of the well at first was about 175 arrels of oil a day; it rose to 240 barrels, and by pumping has been aintained steadily for nearly six months at about 200 barrels a ay.

Soon after this well was brought in, other locations were made Russell and bordering counties. A flow of gas, reported to be 000,000 cubic feet daily, was struck in the Stearns-Streeter Comany's Ed Oswald No. 1 well in the SW¼ SW¼, sec. 8, T. 12 S., R. W., on May 15, 1924. The gas is produced from a sand 10 feet ick, at a depth of 2,461 feet. On June 8 the west offset of the iscovery well, also belonging to the M. M. Valerius Oil and Gas ompany, reached the oil-producing sand struck by the discovery ell, and after being drilled but 10 feet into the "pay" was variusly reported as being capable of producing from 500 to 1,600 arrels of oil a day. It is reported to have yielded, by swabbing, 260 barrels in a 19-hour test. This well is now[3] yielding 350 barrels a day. In the same week the Stearns-Streeter Company's Ed Oswald No. 1 was brought in as an oil well. After being drilled only 1 foot into the "pay" it was reported to be yielding oil at the rate of 25 or 30 barrels an hour. This well now [3] furnishes gas for drilling on near-by leases and produces 750 barrels of oil a day. A well known as the M. M. Valerius Oil and Gas Company's Muncell No. 1, drilled south of the discovery well, was reported on June 14 to be 1 foot into the "pay" and to contain 2,400 feet of oil. This well is now [3] yielding about 100 barrels a day, but is probably capable of producing at least twice this much when the hole is cleaned out. At the time this report was written [3] at least three other wells drilling on the Fairport-Natoma anticline are rapidly approaching the producing sand. At least 20 wells are now [3] either located, drilling or producing oil in Russell county. One other well in Russell county has reached the horizon of the sand that produces oil on the Fairport-Natoma anticline, but has struck no oil. This is the Phillips No. 1 well of the M. M. Valerius Oil and Gas Company, in the SW¼ SW¼, sec. 3, T. 13 S., R. 13 W.[3]

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[3] As of July, 1924, press reports indicate that at the date this bulletin is being sent ress (April 15, 1925) that there are sixteen wells in Russell county producing oil, all except e in secs. 5, 8, 17 and 18, T. 12 S., R. 15 W. One well is in sec. 29, T. 11 S., R. 15 W. All producing wells are located on the Fairport-Natoma anticline. Approximately 1,600 rrels of oil are being shipped from the field daily. More than a dozen additional operations, her drilling or building rigs, are in progress in the near vicinity of the producing wells. Two lls are drilling several miles east of the pool. Twelve wells have been drilled in the county d abandoned, each having penetrated the rocks that produce oil in the wells described ove. One well in eastern Ellis county, three miles west of the producing field, failed to tain commercial production. More than a dozen wells are drilling in Kansas west of ssell county.

Recent drilling of wells in the Russell pool below the two producing horizons of the scovery well have shown the presence of a porous limestone a short way below the lower the two "pays" that is barren of oil, and another porous limestone approximately 75 feet low the "Oswald" pay that gives some promise of production.

CHARACTER OF THE OIL.

The oil produced from the discovery well has a gravity of about 41 degrees Baumé. The producing rock is limestone which is parted near the middle by a bed of shale 1½ feet thick. According to report the oil produced above the shale had a temperature of 38 degrees Fahrenheit, and that produced below had a temperature of 70 degrees. Such a difference is unusual.

A sample of the oil from the discovery well, collected July 7, 1924, was analyzed by the Bureau of Mines, Department of the Interior, at the Bartlesville, Okla., office. The oil is of unusually light gravity for Kansas oils,[4] and its content of gasoline and naphtha is correspondingly large. However, the amount of asphalt, as indicated approximately by the Conradson carbon residue test, and termed *carbon residue of residuum* in the analysis, is somewhat larger than usual.

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[3] See note 3 on page 13.

[4] Dean, E. W., Cooke, M. B., and Bauer, A. D.: Properties of typical crude oils from the producing fields of Kansas: Bur. of Mines Serial No. 2322, 1922.

SAMPLE NO. 24713. Taken from lead line when well was pumping approximately 200 bar-
ls of oil a day. M. M. Valerius Oil and Gas Company's C. C. Oswald well No. 1, SW¼
E¼, sec. 8, T. 12 S., R. 15 W. Specific gravity, 0.820. A. P. I. gravity, 41.1° (Baume
avity, 41.4°). Per cent sulphur, 0.41. Per cent water, nil. Saybolt Universal viscosity at
)° F., 45 sec. Saybolt Universal viscosity at 100° F., 20 sec. Pour point, below 5° F.
irst drop at 37° C.

Temperature, deg. C.	Air distillation barometer 739 mm.			Vacuum distillation at 40 mm.				
	Fraction per cent.	Total per cent.	Specific gravity.	Fraction per cent.	Total per cent.	Specific gravity.	Viscosity.	Cloud test, deg. F.
) to 50	1.9	1.9						
0 to 75	3.1	5.0	.681					
5 to 100	5.8	10.8	.701					
0 to 125	6.7	17.5	.728					
5 to 150	6.0	23.5	.745					
0 to 175	5.3	28.8	.762					
5 to 200	4.3	33.1	.778	3.7	3.7	.842	41	
0 to 225	5.3	38.4	.795	5.3	9.0	.852	46	32
5 to 250	5.5	43.9	.809	4.1	13.1	.866	60	50
0 to 275	6.4	50.3	.823	4.8	17.9	.885	83	66
5 to 300				5.0	22.9	.892	144	80

Residuum. 23.8 per cent. Distillation loss, 3 per cent. Carbon residue of residuum, 11.7 per cent. Carbon
idue of crude, 2.8 per cent.

APPROXIMATE SUMMARY.

	Per cent.	Sp. gr.	°A. P. I.	Viscosity.
ght gasoline (end point 212° F.)	10.8	.692	73.0	
tal gasoline and naphtha	33.1	.731	62.1	
rosene distillate	17.2	.810	43.2	
s oil	7.8	.847	35.6	
nviscous lubricating distillate	9.1	.856–.886	33.8–28.2	50–100
edium lubricating distillate	6.0	.886–.896	28.2–26.4	100–200
scous lubricating distillate				Above 200
siduum	23.8	.965	15.1	
stillation loss	3.0			

ROCKS EXPOSED.

The surface rocks in Russell county are all included in the Cre-
ceous and Cenozoic divisions of geologic time. They are younger
ian the stratified rocks of central and eastern Kansas, the equiva-
nts of which in Russell county are buried more or less deeply. The
llowing table shows the rock formations of this area in order from
oungest (at the top) to oldest (at the bottom), including the main
ivisions of the rocks concealed below the surface as well as those
hich are exposed. Rocks older than the Dakota sandstone are not
posed, but were identified by M. N. Bramlette from a study of well
ittings and drillers' logs.

Table of rock formations in Russell county, Kansas.

Era	System and series.		Group, formation, and member. [a]		Lithologic character.	Thickness in feet.
CENOZOIC.	QUATERNARY.	Recent.			Alluvium, soil and talus material. Lower terrace deposits and gravels along streams.	0–50
		Pleistocene.	McPherson (?) formation.		Upper gravel deposits along main streams.	
	Tertiary (?).		Ogallala (?) formation.		High gravels on divides.	
MESOZOIC.	CRETACEOUS.	Upper Cretaceous.	Niobrara formation.	Smoky Hill chalk member.	Clayey chalk and chalky shale, with scattered ferruginous concretions.	0–50
				Fort Hays limestone member.	White or tan massive chalk beds.	55
			Carlile shale.	Blue Hill shale member.	Gray fissile clay shale, containing concretions, with sandstone near the top.	215
				Fairport chalky shale member.	Chalky shale and thin beds of chalk.	85
			Greenhorn limestone.	Upper member.	Chalky shale containing thin beds of chalk.	20
				Jetmore chalk member.	Alternating thin chalk beds and chalky shale.	20
				Unnamed member.	Chalky shale with a few thin beds of chalk.	28–40
				Lincoln limestone member.	Chalk, chalky shale, and thin beds of hard crystalline limestone.	20–25
			Graneros shale.		Dark bluish clay shale.	40
			Dakota sandstone.		Variegated and gray clay and sandy shale and evenly bedded sandstone. Exposed in Russell county, 160 feet.	300–400
				Rocktown channel sandstone member.	Lenses of cross-bedded sandstone in upper 125 feet of formation.	
		Lower Cretaceous (?).			Bluish shale and brown sandstone containing leaves and marine invertebrates; exposed in western Saline county; may possibly extend under the Dakota of Russell county.	

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a. A lithologic term, like sandstone or limestone, that is in current usage for a formati or member, has customarily been applied in local areas if this lithologic name emphasizes important characteristic of the unit or if this lithologic type is the conspicuous one in t exposures, even though a large part of the unit is some other rock. Although the litholog terms in the names, Smoky Hill chalk, Fort Hays limestone, Greenhorn limestone, and Dako sandstone, are not exactly descriptive of these units in Russell county, they are used, in a cordance with this custom, in this report.

TABLE OF ROCK FORMATIONS IN RUSSELL COUNTY, KANSAS—CONCLUDED.

ra.	System and series.		Group, formation, and member. *b*.		Lithologic character.	Thickness in feet.
PALEOZOIC.	CARBONIFEROUS.	Permian.	Cimarron group.		Predominantly red sandstone, and shale with anhydrite, and gypsum beds at some horizons.	400-600
			Sumner group	Wellington formation.	Gray shale, with anhydrite and massive rock salt.	300-400
				Marion formation.	Gray shale, anhydrite, and dolomite; red beds with fossiliferous cherty limestone in lower part.	400
			Chase formation.			
			Council Grove formation.		Shale, limestone, and red beds.	400
		Pennsylvanian.	Wabaunsee formation.		Blue shale, and thin beds of limestone and sandstone.	450
			Shawnee formation (to base of Topeka limestone member).			
			Shawnee formation (from base of Topeka limestone).		Limestone and small amounts of shale and sand. Yields oil in Russell county.	300
			Douglas formation (to base of Oread limestone member).			
			Pennsylvanian formations below the Oread.		Fossiliferous limestones and gray shales.	100-400
		Carboniferous (Pennsylvanian or earlier).			Shale, red rock, and thin limestones.	150±
		Ordovician (and earlier?).*			Shale, red rock, and cherty, sandy dolomite, containing Ordovician fossils at top.	500±

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b. The United States Geological Survey classifies the units above the Cherokee shale as roups instead of formations, and divides the Marmaton into two major units—the Pleasanton nd Henrietta groups.

* Unweathered fragments of granite were found by C. S. Ross, of the United States Geogical Survey, in drill cuttings from the Producers and Refiners Oil Corporation, Haise No. 1 ell, NW¼ SE¼, sec. 24, T. 12 S., R. 15 W., Russell county, from depths of 3,628 to 3,632 et, nearly 700 feet below the Oread limestone. Although the rock penetrated is probably anite, it may possibly be arkose, a sedimentary rock made of granite pebbles.

Cenozoic.

The outcropping Cretaceous rocks in Russell county are overlain discontinuously by deposits of sandstone, gravel, and silt of Cenozoic age. In date of formation these rocks range from Recent to probably late Tertiary. Careful study of these scattered deposits was not attempted in the field because their possible economic value is not related to the oil and gas resources. They may be classified in the order shown in the table.

Recent.

ALLUVIUM, SOIL, AND TALUS MATERIAL.

A veneer of rock material is now being formed throughout Russell county. This veneer includes the alluvium that is accumulating in the channels and lower valleys of nearly all the larger streams, especially in the parts of Smoky Hill and Saline valleys where the river meanders. On the flat uplands and the gentle south slopes of the broad divides a mantle of soil a few feet thick, largely residual, is also being formed. The lithology of the soil varies in detail from place to place, but generally corresponds with that of the underlying bedrock. Its composition is considered more fully in the descriptions of the exposed subdivisions of the Cretaceous strata. Heaps of more or less weathered talus material abound at the bases of bluffs formed by the Dakota, the Niobrara, and especially the Greenhorn formation.

LOWER TERRACE DEPOSITS.

Along Saline river and its larger tributaries, and less conspicuously along Smoky Hill river, a persistent terrace rises about 20 feet above the level of the streams. The deposits on this terrace are noted for their fertility, and form the soil of some of the best farms in the region. These deposits are conspicuously developed on the wide flat near the mouth of Paradise creek, in the western part of T. 12 S., R. 13 W.

The smaller tributaries throughout the county have recently cut into their stream beds and developed a terrace that may possibly be correlated with the 20-foot terrace of the Saline river valley.

Dune Sand (?).

Large deposits of dune sand lie in the valleys of some of the larger reams of western Kansas. No deposit of this type was found in ussell county, unless a few sod-covered sandy knolls on the north ink of Smoky Hill river are ancient dunes.

Pleistocene.

Gravel Deposits of Saline and Smoky Hill Rivers.

Subdivisions of the gravels. In the valleys of Saline and Smoky ill rivers and their larger tributaries there are deposits of coarse avel, which lie from 20 to 70 feet above the present streams. Vol-nic ash was found near the top of such gravel beds north of Smoky ill river. Along Saline river these beds can be subdivided into posits at two levels: (1) the lower, and presumably younger, avel ("Salt Creek gravel beds" of Logan[1]), which occurs rather iformly about 50 feet above the present stream grades; and (2) e higher beds, which lie from 40 to 70 feet above the present reams. Where the two occur in the same section the lower gravel about 15 feet below the higher.

Lower gravel beds on Saline river. The lower gravel is found at any places in northwestern Russell county, especially near the outh of Salt creek, 5 miles north of the town of Russell. The de-sit forms a stratum that is well cemented with lime, persistent er small areas and averages about 2 feet in thickness. It is in any places steeply crossbedded from the west and is composed iefly of quartz pebbles, but at some places it contains abundant esh fragments of pink orthoclase and flat pieces of chalk, some of hich inclose *Inoceramus* shells. The individual pebbles range in ameter from a thirty-second of an inch to an inch.

Upper gravel beds on Saline river. Beds of unconsolidated gravel, feet or more thick, of essentially the same composition as the wer gravel beds, but containing a few lenticular beds of sandy ay about a foot thick, are found along Saline river. This gravel quarried north of Russell, and used locally in making cement. ossibly because the beds are less consolidated, cross-bedding is not conspicuous in them as it is in the lower gravel.

Gravel beds near Smoky Hill river. Along the north bank and e tributaries of Smoky Hill river beds of gravel about 10 feet thick, very similar to the upper beds of gravel on Saline river, are in some places found at levels ranging from 20 to 60 feet above the streams. This gravel consists chiefly of quartzite pebbles, some of which are made shiny by "desert varnish," bits of silicated wood, granite, basaltic rock and chert, and beds composed almost solely of flat, unweathered fragments of chalk about an inch across, deposited so as to show an imbricated structure. These gravel beds contain grains of pink feldspar, and are poorly sorted, the most abundant grains ranging in diameter from about 0.5 to 3 millimeters.[2] Some of the beds are slightly cemented with calcium carbonate. This gravel is quarried for local use as construction material. South of the town of Russell there are springs and large seeps at the base of this gravel.

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[1] Logan, W. N.; The Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 218-9; 1897.

Volcanic ash. On the west side of a small valley near the southwest corner of sec. 19, T. 14 S., R. 13 W., a lenticular bed of volcanic ash more than 5 feet thick is exposed for over 350 feet horizontally in the upper part of the gravel beds near Smoky Hill river, just described. The ash is white to cream colored and is very thin bedded. It lies with sharp contact on a bed of chalk pebbles, but its upper limit is obscured.

The grains of the ash are extremely small and very angular. Under the microscope they are seen to possess the vitroclastic and cellular texture and the isotropic optical properties characteristic of volcanic ash. The beds may be identified in the field by their inactivity with hydrochloric acid and the abundance of minute surfaces that reflect light (which distinguish them from loose lime), and by the extreme fineness and angularity of the grains, and their loose, unconsolidated texture (which distinguish them from sandstone).

No other deposit of volcanic ash was found in Russell county. In a well dug near the courthouse at Russell a bed of white, powdery substance 4 feet thick was encountered 8 feet below the surface and was reported to have "blown away when thrown out upon the ground." This may have been either volcanic ash or loose lime.

FOSSILS.

On the west side of Fossil creek, north of Smoky Hill river, in the southeast corner of sec. 25, T. 14 S., R. 14 W., in Russell county, J. L. Phinney, a resident of Russell, while excavating in a bed of ravel near some springs there, found a large tooth and a few bones. Ir. Phinney gave these fossils into the keeping of the writers until nally stored in the State Museum at Lawrence. He kindly acompanied the writers to the place where they were found, and rough his guidance some additional bones were collected. J. W. idley, of the United States National Museum, to whom the fossils ere submitted for identification, reported on them as follows:

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[2] See Seaton, R. A., and Taylor, I. I.; Tests of Kansas sands for use in mortar and concrete; Kansas State Agr. Coll. Eng. Experiment Sta. Bull. 3, pp. 10, 16, 38; 1916.

> “The broken tooth is a left lower molar of an extinct species of elephant. seems to belong to the species known as *Elephas imperator*. The three linters of bone are from the central portion or shaft of a metatarsal (the one between the hock joint and the fetlock) of an extinct species of horse osely related to the domestic horse of the present day. Both these animals ed in the early part of the so-called ‘Ice Age.’ ”

No other fossils except Cretaceous forms contained in pebbles of halk were found in any of the Cenozoic deposits in Russell county.

Age and Correlation.

Although it is possible that these fossils may have been entombed earlier deposits made quaggy by seepages of water, their Pleistoene age suggests that the gravel beds may be a part of the Mcherson formation. This formation, formerly called the “Equus eds” because of the occurrence in it of bones of horses, is the only leistocene formation, aside from glacial drift and loess, that has een recognized in Kansas, and its type exposures are but 50 miles the southeast, in McPherson county.[3] The one other gravel rmation recognized in western Kansas is the Ogallala formation,[4] Pliocene and late Miocene age.

The chief lithologic differences reported between these two formaons are the absence of grains of feldspar in the McPherson beds,[5] nd the greater degree of cementation by calcium carbonate in the gallala formation. The gravel beds along Smoky Hill river, in ussell county, are only slightly cemented, and in this respect remble the McPherson formation, but the presence of grains of feldar and of pebbles of igneous and metamorphic rocks gives them a rong likeness to the Ogallala formation. Volcanic ash is reported om the upper parts of both formations, but most of the wellthenticated occurrences appear to be younger than the Ogallala.

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[3] Haworth, Erasmus, and Beede, J. W.; The McPherson Equus beds: Kansas Univ. ol. Survey, vol. 2, pl. XLV; 1897.

[4] Darton, N. H.; U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin Folio (No. 212); 20.

[5] Haworth, Erasmus, and Beede, J. W.; The McPherson Equus beds: Kansas Univ. ol. Survey, vol. 2, pp. 289-290, 295; 1897.

Both formations yield good water, and the springs in the gravel beds near Fossil creek are of no assistance in correlation.

The regional relations and lithology of the McPherson formation in McPherson county indicate that its sediments were deposited by a large stream that flowed southward from the Smoky Hill river to the Arkansas river.[6] Assuming that this interpretation is correct, and using a gradient for the stream of 2½ to 3 feet to the mile (derived from the slope of the upper surface of and the bedrock below the deposits of McPherson county[7]), we would expect the McPherson formation on Fossil creek at the elevation at which the bone-bearing gravel beds are found there. No thick beds of gravel have been reported along Smoky Hill river between Russell and McPherson counties, but such deposits may have existed and been largely removed by erosion or become obscured by the soil cover.

The Ogallala formation lies on a surface that is probably a hundred feet above the fossil-bearing gravel, a fact considered more fully under the heading "High terrace gravels (Ogallala? formation)." It is, of course, possible that the gravel beds on Fossil creek are a representative of a hitherto unrecognized Cenozoic terrane that is neither the Ogallala nor the McPherson formation.

The paleontologic and general lithologic content of the gravel beds on Fossil creek and their regional relations to the two formations point to their correlation with the McPherson formation. The only evidence contravening this correlation is the presence of feldspar and the supposed absence of gravel connecting with the McPherson county deposits. It is possible that these deposits might have been formed at the same time, but in separate areas, and the difference in their lithologic content might conceivably be explained in this way.

The absence of fossils and of volcanic ash and the slightly higher elevation above local grade level are the only features in which the upper gravel beds on Saline river differ from the beds near the Smoky Hill. The gravel beds on Saline river obviously cannot be an actual continuation of the McPherson formation of McPherson county if that formation was deposited by a stream flowing in the valley of the Smoky Hill river, but, in the absence of evidence to the contrary, the upper gravel beds on Saline river are here tentatively classed as contemporaneous with the beds near the Smoky Hill river.

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[6] Haworth, Erasmus, and Beede, J. W.; The McPherson Equus beds: Kansas Univ. Geol. Survey, vol. 2, pp. 290-295; 1897.

[7] Idem, p. 292.

Tertiary (?).

HIGH TERRACE GRAVELS (OGALLALA? FORMATION).

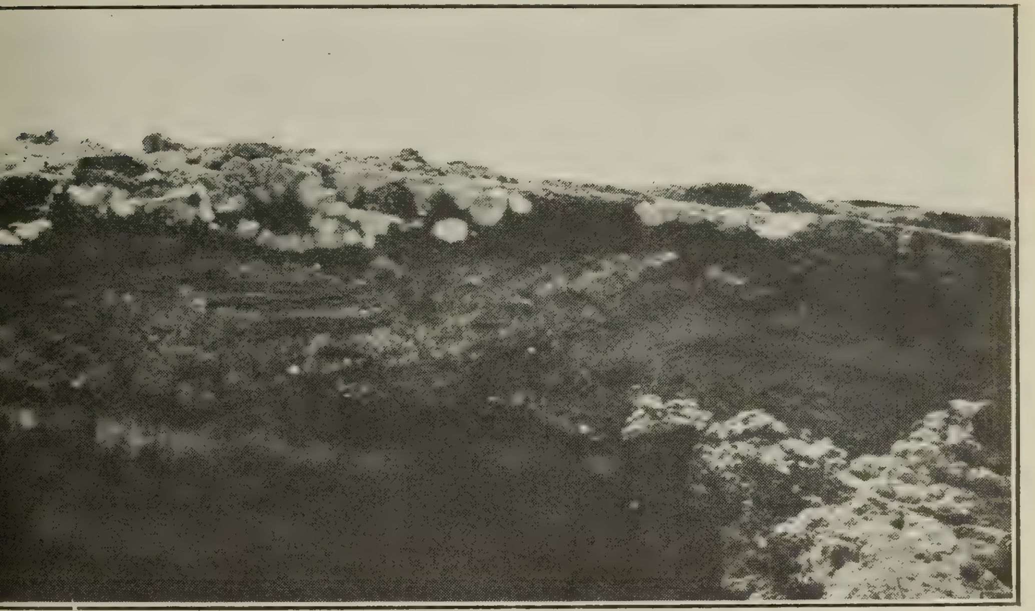

FIG. 2. High terrace gravels (Ogallala? formation) in sec. 18, T. 13 S., R. 5 W., Russell county. View southward, showing cross-bedding and spherical odules of calcium carbonate.

On the higher uplands in the northwestern part of Russell county cattered patches of gravel and grit are found from 70 to 100 feet bove the local grade. Two distinct types are recognizable: (1) eposits of grit and clay several feet thick that are more or less losely cemented with calcium carbonate, and (2) a thin veneer f pebbles and cobbles, the largest 6 inches in diameter. These two ypes appear to grade laterally into each other. The beds of calareous grit[8] show strong cross-bedding and contain more or less pherical masses of soft, pure lime (Fig. 2). The "lime balls" are rom 2 to 8 inches in diameter and a few contain small nuclei of ardened calcium carbonate. The pebbles and gravel in the thin ayer at the same level consist chiefly of quartzite, dense tan limetone, and nodules of hard calcareous material resembling parts of he Ogallala formation farther west.

These beds occur on a more or less dissected surface that slopes ently southward and eastward from the high divides north of moky Hill and Saline rivers and Paradise creek. The gravel in the northwestern part of Russell county lies on a surface that, south of Saline river, slopes gently south-southeastward toward Smoky Hill river at a rate of slightly more than 10 feet to the mile. This surface, though having little or no gravel on it, is more or less distinctly recognizable nearly to Fossil creek, and its extension would probably be about a hundred feet above the fossil-bearing gravel beds there. The highest elevation at which these high terrace gravels were recognized near Russell county is 2,000 feet above sea level, in sec. 34, T. 12 S., R. 16 W., Ellis county, 2 miles west of Russell county, but they were seen at elevations of less than 1,850 feet at places in northern Russell county.

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[8] For an excellent discussion of the origin of calcium carbonate in similar gravels to the est, see: Johnson, W. D.; The high plains and their utilization: U. S. Geol. Survey, 21st nn. Rept., pt. 4, pp. 639-656; 1900.

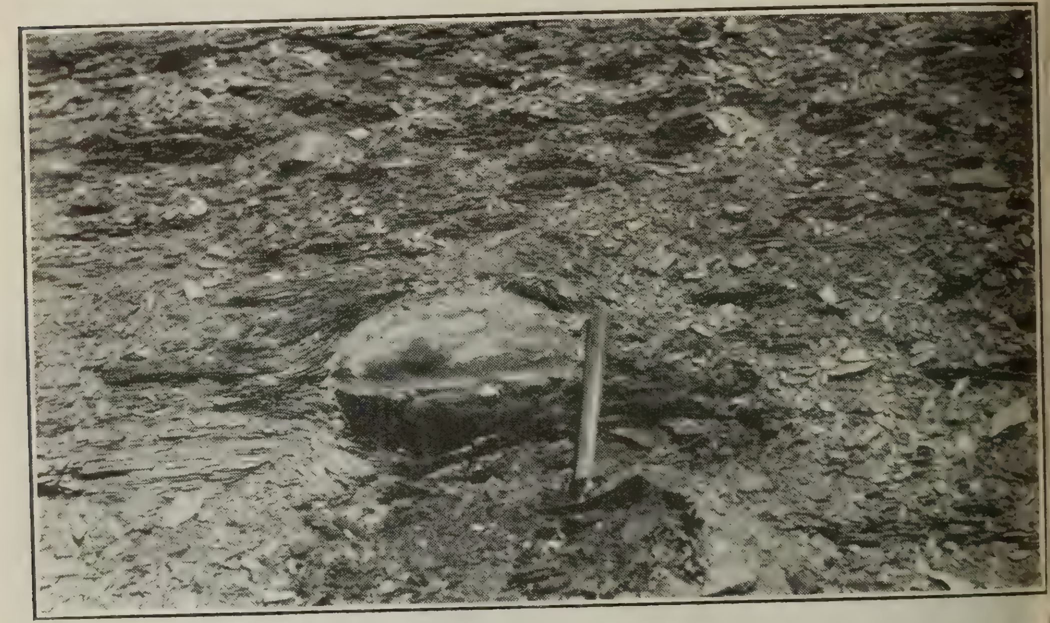

FIG. 3. A concretion in the lower part of the Fairport member of the Carlile shale, 10 feet above its base, sec. 3, T. 12 S., R. 16 W., Ellis county. Note the bending of the shale lamination around the concretion.

The Ogallala formation is widespread in western Kansas as a deposit of coarse materials at high levels.[9] It consists of gravel containing pebbles of igneous rock and much reddish feldspar, sand that is commonly cross-bedded, and clay and silt, and is irregularly cemented with calcium carbonate throughout.[1] The Ogallala formation is the platform of debris built by overladen rivers flowing eastward from the Rocky Mountains,[2] and its upper surface should therefore be nearly a plane. Elevations throughout western Kansas show that the formation slopes eastward at an average rate of slightly more than 10 feet to the mile. To the west this slope is teeper, but eastward it becomes flatter. The base of the Ogallala s lower in the present large valleys than it is on the divides,[3] indicating that the present main lines of drainage are of pre-Ogallala age.

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[9] Darton, N. H.; U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin Folio (No. 212); 1920.

[1] Haworth, Erasmus; Physical properties of the Tertiary: Kansas Univ. Geol. Survey, vol. 2, pp. 247-284; 1897.

[2] For an especially complete discussion of the origin of this and related formations, see: Johnson, W. D.: The high plains and their utilization: U. S. Geol. Survey, 21st Ann. Rept., pt. 4, pp. 612-656; 1900.

If the formation once extended farther east into Russell county —and it has been recognized north, west and south[4] of there—its elevation should be approximately 2,000 feet in the western part of he county and less than 1,800 feet in the eastern part, lying somewhat lower in the larger valleys than on the broad divides. The oincidence in elevation and slope, and the striking similarity of the ithology of the high terrace gravels of Russell county to those of he Ogallala formation, appear to justify their correlation with that ormation.

Uselessness of Cenozoic Rocks for Structural Mapping.

No evidence was found to prove that the Cenozoic beds may not ave been warped slightly by earth movements, or by settling of the buried strata during Recent time, but the discontinuity of the deposits and their irregular, unconformable contact with Cretaceous ocks, make them useless for structural mapping.

Mesozoic.

Cretaceous.

NIOBRARA FORMATION.

The Niobrara formation, consisting of a series of chalky beds, rops out only in the extreme northwest corner of Russell county, where a maximum thickness of about 100 feet remains uneroded. The lower part consists of massive beds of chalk containing few impurities, white and rather soft above and tan and harder below; the pper part consists of beds of soft chalk and chalky marl, silty and ron-stained.

The stratigraphic position, lithology and fossils of this formation stablish its correlation with the Niobrara of Colorado, Wyoming,

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[3] Darton, N. H.; Syracuse-Lakin Folio (No. 212): U. S. Geol. Survey Geol. Atlas, 5; 1920.

[4] Haworth, Erasmus; Special report on the well waters in Kansas (geologic map of ansas); Univ. Kansas Geol. Survey, Bull. 1, pl. 1; 1913.

South Dakota and Nebraska, and make highly probable its correlation with the Austin chalk of Texas.[5]

The formation was named by Meek and Hayden,[6] in 1861, from exposures near the mouth of Niobrara river in northeastern Nebraska. The Niobrara formation in Kansas has been subdivided into the Smoky Hill chalk member above and the Fort Hays limestone member below.

SMOKY HILL CHALK MEMBER.

Character and distribution. The argillaceous Smoky Hill chalk member of the Niobrara formation occurs only as thin remnants capping the higher hills in the northwestern part of the county. It consists of soft beds of chalky marl containing scattered ferruginous concretions and alternating thin beds of chalk rock, which together reach a maximum thickness of nearly 50 feet in Russell county.

Clear exposures of this member were not found in Russell county, but the exposures seen indicate that its composition is similar to that of beds found 30 miles to the west, in sec. 17, T. 11 S., R. 20 W., Ellis county, where the lower 90 feet or so of the Smoky Hill member—a soft chalky shale and alternating harder beds of chalk, and some very thin layers of clay—is exposed. Flat, more or less circular, impure limonitic concretions, many of which are about a foot in diameter in the plane of bedding and 3 or 4 inches thick, occur throughout the member, but are most abundant in the lower 30 feet. These concretions contain a central core of slightly weathered pyrite several inches in diameter and an inch thick, and at least some of them contain nuclei of thick *Inoceramus* shells. The cubical faces of the pyrite crystals are commonly a half to a quarter of an inch in diameter. G. E. Patrick[7] found that chalk beds of this member contain 84 to 98 per cent of calcium carbonate, and crude quantitative analyses made by the senior author show that some of the marly beds contain about 50 per cent of lime.

The marly parts of the Smoky Hill member are separated into thin beds by clayey partings, but the harder and less numerous chalk beds are commonly massive. The marly beds appear to soften and the chalk rocks to harden somewhat on weathering, so that on the freshest surfaces the two types are almost indistinguishable. Fresh exposures of the rocks are white, pale cream, or bluish gray, but eathered surfaces have a yellowish tint, which ranges from a bright n to a light cream. The concretions weather to a conspicuously rker rusty brown.

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[5] Stanton, T. W.; Later Mesozoic invertebrate faunas: Jour. Geology, vol. 17, p. 419; 1909.

[6] Meek, F. B., and Hayden, F. V.; Descriptions of new lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary fossils collected in Nebraska Territory [etc.]: Phila. Acad. Nat. Sci. Proc. for 1861, vol. 13, pp. 419-42; 1862.

[7] Patrick, G. E.; Kansas chalk: Kansas Acad. Sci. Trans., vol. 4, pp. 13-15; 1875.

Joints are not readily recognizable in the member because of poor posures, but at some localities outside of Russell county faults ith displacements ranging from a fraction of an inch to a few feet e conspicuously marked by slickensided, coarsely crystalline veins calcite, 1 to 6 inches thick. Mudge[8] mentions the occurrence of ystals of barite in some of these veins.

Fossils.[9] Large, thick, rather flat and coarsely ribbed shells, for- erly referred to the genus *Haploscapha* Conrad, but now placed in e genus *Inoceramus,* are abundant from the base of the Smoky ill upward, but were not found below that member. This *Inocera- us* has been designated by three specific names in the literature— *andis* Conrad, *eccentrica* Conrad, and *niobrarensis* Logan—but is very likely that the three are not distinct and should be in- uded under the one name *I. grandis.* The small shells of the lonial oyster *Ostrea congesta* Conrad are common throughout the posed portion of the member. Vertebrate remains, largely frag- ents of bone, have been found at many places, and the member ntains abundant *Globigerina bulloides* D'Orbigny and *Textularia obulosa* Ehrenberg.

Means of recognition. The Smoky Hill chalk member does not rm prominent topographic features in the eastern area of its out- op, but makes long, gentle, sodded slopes with few exposures, nched by thin beds of chalk along the larger streams where vigor- s tributaries have cut into it. The residual soils derived from the ember range from gray to black, their color depending somewhat on the siltiness of the underlying bed, but chiefly upon the ex- nt to which the lime has been extracted by leaching and upon the nount of organic matter that has accumulated at the surface.

The Smoky Hill member, which somewhat resembles several other bdivisions of the Cretaceous of central Kansas, can be more or s readily distinguished from the Greenhorn limestone and the rt Hays member of the Niobrara formation by its persistently llower color and the absence of numerous thick beds of chalk rock occasional thin beds of crystalline limestone. The Fairport alky shale member of the Carlile shale, which it most closely re- mbles, contains fewer beds of chalk rock and no limonitic con- etions.

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[8] Mudge, B. F.; Notes on the Tertiary and Cretaceous periods of Kansas: U. S. Geol. Geog. Survey Terr., Bull. 2, p. 215; 1876.

[9] The discussion of fossils is based on identifications made by J. B. Reeside, Jr.

Difficulty of mapping. Detailed mapping of individual beds within the Smoky Hill member is practically impossible except along the larger stream courses, where adequate exposures permit their actual tracing or the recognition of distinctive sequences of beds. Throughout the remainder of its area the structure of the rocks can be determined only by shallow drill holes that penetrate to some easily recognizable horizon, such as the top of the Carlile shale—a slow and costly method.

Name. The Smoky Hill chalk member of the Niobrara formation was first known as the "*Pteranodon* beds,"[1] but later was named by Cragin[2] from Smoky Hill river, in Kansas. Geographic names are now preferred to paleontologic names for designing formations, and the term Smoky Hill is to-day in good standing. Cragin subdivided the Smoky Hill member into four parts—the bluish and marly "Trego zone" at the base, the yellow and more chalky "Norton zone" next above, the Graham jasper next, and a thin unnamed subdivision at the top. Williston,[3] later, in 1896, proposed to subdivide the Smoky Hill into two submembers—the "*Rudistes* beds" below and the "*Hesperornis* beds" above. Probably the portion of the member exposed in Russell county is equivalent to parts of the "Trego zone" of Cragin and the "*Rudistes* beds" of Williston.

FORT HAYS LIMESTONE MEMBER.

Character and distribution. The rim of the highest buttes in the northwest corner of Russell county is made by the Fort Hays limestone member of the Niobrara formation. This member, somewhat more than 50 feet thick, is in this area made up of massive beds of chalk, white and rather soft above and tan and harder below.

Complete exposures of this member were not found in Russell county, but partial sections found at a number of places near by indicate a widespread similarity of detail. Near the northwest corner of Ellis county the Fort Hays member appears to be about 55 feet thick, and this is probably near its average thickness in the area here considered.

The uppermost beds, where fresh, are commonly pure white, moderately hard, massive chalk, which weathers white or pale cream and develops a thin-bedded structure. Individual chalk beds of greater purity and hardness than the remainder are apparently ost numerous near the middle of these white beds. Small limonitic ncretions with nuclei of pyrite occur in the upper part. These pper beds are 20 to 30 feet thick.

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[1] Credited to Marsh by Williston, S. W.; Smoky Hill chalk: Kans. Univ. Quarterly, vol. 4, p. 251; 1896.

[2] Cragin, F. W.; On the stratigraphy of the Platte series, or the Upper Cretaceous of the Plains: Colo. Coll. Studies, vol. 6, pp. 51-52; 1896.

[3] Williston, S. W.; Idem, p. 252.

The intermediate, or, in a few places, the basal beds of this mem- r are harder and form more or less prominent bluffs of massive ds, 1 to 6 feet thick, of tan to dull buff chalky limestone. The ck is rather uniformly a light cream where fresh and it contains me thinner-bedded portions. Small limonitic balls about a quarter an inch in diameter are sparingly distributed through the lower rt. This unit is from 15 to 30 feet thick and probably averages out 20 feet in thickness in Russell county.

Farther west, at one or two localities in Ellis and Trego counties, e basal 20 or 30 feet of the Fort Hays member is softer and inner bedded and contains layers of chalky shale. Slightly sandy yers; long, narrow, vertical worm tubes; and "conglomerates" ade of fragments of *Inoceramus* shells, occur in some places. This ase appears to become thinner toward the east, until near Russell unty it is absent or is represented by but 2 or 3 feet of soft, grit- s chalk.

The hard beds throughout the Fort Hays member readily soil the gers with a white chalky powder and especially the white upper ds easily leave a white mark. The rock contains Foraminifera of e *Globigerina* types, which, however, are apparently not common, e bulk of the rock being made up of very fine white grains of wder, 0.01 millimeter or less in diameter. These features[4] appear make the lithologic name *chalk* or *chalkstone* more appropriate an the more general or more technically restricted term *limestone*.

This member, like the overlying Smoky Hill, is sufficiently brittle resist slight deformation, and in places it has yielded to pressure gravity by breaking, so that small faults are not uncommon in eas of its outcrop. The Fort Hays member is unique among the ata of central Kansas in its decided propensity to slump. Great ocks of the basal beds may be seen lying as much as 50 feet below eir normal position. This slumping, however, is rarely accom- nied by great fracturing of the rock.

Some indication of an unconformity at the base of this member s found near the northwest corner of sec. 32, T. 11 S., R. 16 W., lis county, 5 miles west of Fairport. Here vertical cracks, three- hths of an inch wide, filled with fragments of the Fort Hays lime- ne, extend 20 feet into the underlying sandstone bed of the

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[4] De Lapparent, J.; Leçons de petrographie: pp. 359-361, Masson et Cie, Paris; 1923.

Carlile shale. It is probable that these filled joints are merely fractures formed by slumping.

Fossils. The thick-shelled, rather regular, and deeply cupped *Inoceramus deformis,* about 8 inches in diameter, and *Ostrea congesta*[5] occur throughout the member, but are especially abundant in its lower part. Except for the microscopic *Globigerina* and *Textularia,* no other fossils were noted in this member.

Topographic prominence. The Fort Hays member is topographically one of the most prominent of the rock units in central Kansas. As it is harder than the thick underlying beds of the Carlile shale, its lower part at many places caps an irregular line of hills that stand 100 feet or more above the surrounding country. Isolated buttes, some small and nearly conical, others long and flat-topped, are rather common near the boundary of the member with the Carlile shale, and some stand at distances of nearly a mile from it. A gentle upland slope, almost invariably developed on the upper softer beds, at many places reaches nearly to the base of the member. The upper part of the member is rarely well exposed, and is at most places represented by a white or light limy soil in which small chips of chalk are usually abundant. On the weathered south slopes of the divides and in similar areas of local relief the lower beds make a fairly conspicuous bench of very light tan soil that is relatively barren of vegetation. The severe slumping of the basal beds of the Fort Hays member gives rise to a distinctive topographic form that is misleading from a distance. At some places on the steeper bluffs below the Fort Hays scarp several lines of prominent benches or terraces may be seen, which when examined closely are found to be made by long slumped ledges of Fort Hays chalk that dip steeply back toward the hill and form bands of narrow undrained depressions behind them. Because of the moisture retained in these troughlike depressions, the vegetation grows more rankly in them than on the bordering slopes.

Means of recognition. The Fort Hays member somewhat resembles in its lithology the Smoky Hill member of the Niobrara, the Fairport member of the Carlile, and the Greenhorn limestone, all chalky. From the Fairport and Smoky Hill members it is distinguishable by its thick beds of hard chalk, the light color of its weathered surfaces, and the presence of clay shales below. The Greenhorn formation has thinner hard chalk beds, many layers of chalky marl, and thin beds of coarsely crystalline dark gray limetone near its base, and is about twice as thick as the Fort Hays nember.

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[5] Identifications by J. B. Reeside, Jr.

The contact of the Fort Hays limestone member with the overying Smoky Hill chalk member is at many places difficult to ecognize. Typically the lower beds of the Fort Hays member make fairly prominent scarp, showing tan, hard, more or less massive eds of chalk or a light-colored soil sparsely strewn with small chips f hard chalk on which vegetation grows sparingly. Above this carp the upper beds of the member form a gentler slope of very ght soil. The Smoky Hill, however, almost uniformly makes a ery gentle slope of dark clay soil, and in good exposures presents nall scarps of conspicuously tan, soft, relatively thin-bedded chalky hales. Large limonitic concretions are abundant in the lower part f the Smoky Hill, but similar though much smaller ones are found the upper part of the Fort Hays member. Because of its superior ardness and whiteness in contrast with the beds immediately overing, the top of the Fort Hays member is usually recognized by rillers in well borings.

Unreliability of the Fort Hays member for detailed mapping. Its pographic prominence and more or less distinctive characteristics ight seem to make the Fort Hays member a valuable unit for etailed structural mapping. Unfortunately, however, except for ie general subdivisions of white and softer beds above and yellow id harder beds below, it is very difficult to recognize any of its inividual components for distances sufficient to make their mapping rofitable. The top of the basal Fort Hays bluff is held by the ime bed for short distances only—a fact all too apt to be overoked in mapping areas where exposures are poor. On many of the naller isolated buttes near the Fort Hays-Carlile contact the capng basal Fort Hays strata are tilted and are rarely at the proper evations for this horizon as judged from surrounding outcrops; id one is forced to the conclusion that even the narrower projecting ms of the Fort Hays member show the same tendency, for the rata gradually rise along these spurs to the main divides. These oservations have led the writers to the conclusion that in areas poor exposures the only uniformly reliable horizon in this member r detailed structural mapping is its contact with the underlying arlile shale, and to the belief that even this contact is not reliable narrow divides and isolated hills where small areas of the member ay have slumped below their normal position. Shallow drill holes er much of the flat uplands might be used profitably to determine e structure of the beds at places where deformation is suspected.

Name. Because of an earlier miscorrelation by Hayden of the chalk beds at Wilson, Kan., Mudge, in 1876,[6] tentatively applied the name "Fort Hays division or group" to all the strata from the top of the Dakota to the base of the present Smoky Hill member of the Niobrara formation, being in doubt as to presence of the Benton in Kansas. Williston,[7] in 1892, restricted Mudge's name to the present Fort Hays member, and although Cragin[8] later proposed the name "Osborne limestone" for the same unit, Fort Hays has been used by all other writers on western Kansas since 1893.

The Term Benton.

"Fort Benton group" was the name applied by Meek and Hayden,[9] in 1861, to the Cretaceous strata (their No. 2) between the Dakota and the Niobrara. The name, which was taken from Fort Benton, Mont., continued to be used in that form for many years, but was finally shortened to Benton shale where the rocks are indivisible and to Benton group where they are divisible. The term Benton was long used for the corresponding unit in Kansas, but Logan,[1] in 1897, made comparisons with the Carlile, Greenhorn and Graneros formations of Colorado, and in 1899[2] he made these correlations more positively. Darton,[3] however, in 1904, was the first to apply these Colorado names in Kansas, retaining Benton as the group name for the three formations. The United States Geological Survey, however, many years ago abandoned the use of the term Benton group, because the Carlile, Greenhorn and Graneros formations, together with the overlying Niobrara formation, compose the Colorado group—a broader and more useful group name.

Carlile Shale.

About 300 feet of argillaceous and chalky shale that crop out in Russell county between the Niobrara and Greenhorn formations nake up the Carlile shale. The entire thickness of the formation emains in only a small area in the northwest corner of the county, but the lower 20 to 50 feet is found on the flat uplands that comprise a large part of its area. The formation was named by Gilbert[4] from exposures at Carlile Spring and at Carlile, Pueblo county, Colorado. In general the Carlile shale is argillaceous, but in its upper part it contains calcareous and ferruginous concretions, and in ts lower fourth or third it is highly calcareous, and includes thin beds of chalk. This formation was conspicuously in the public eye or a few years before and after 1900 as the "gold shales" of western Kansas. Mills were erected in Ellis and Trego counties to recover old and silver thought to exist in them in small quantities, but lthough minute traces of both metals were found in some samples f the shale, none contained sufficient quantities to make their mining profitable.[5] The Carlile shale in Russell county has been subivided into the Blue Hill shale member above and the Fairport halky shale member ("Ostrea shales") below.

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[6] Mudge, B. F.; Notes on the Tertiary and Cretaceous periods of Kansas: U. S. Geol. and Geog. Survey Terr. Bull. 2, pp. 218-221; 1876.

[7] Williston, S. W.; The Niobrara Cretaceous of western Kansas: Kans. Acad. Sci. Trans. for 1891-1892, vol. 13, pp. 108-109; 1893.

[8] Cragin, F. W.; On the stratigraphy of the Platte series [etc.]: Colo. Coll. Studies, vol. 6, p. 51; 1896.

[9] Meek, F. B., and Hayden, F. V.; Description of new lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska Territory [etc.]: Phila. Acad. Nat. Sci. Proc. for 1861, vol. 13, pp. 417-422; 1862.

[1] Logan, W. N.; The Upper Cretaceous of Kansas: Kan. Univ. Geol. Survey, vol. 2, pp. 232-234; 1897.

[2] Logan, W. N.; A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geology, vol. 7, pp. 83-91; 1899.

[3] Darton, N. H.; Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 445; 1904.

BLUE HILL SHALE MEMBER.

More than 200 feet of gray, fissile, clay shale, containing beds of alcareous and sideritic concretions, constitute the Blue Hill ("Vicoria") shale member of the Carlile shale. This member crops out n the higher ridges in the northwestern eighth of Russell county. t is strikingly uniform throughout, the chief vertical differences eing in the number, size and composition of the calcareous concreons—those in the lower part being smaller, flatter, and more feruginous—and in the presence of a bed of sandstone at the top. Its recise thickness is difficult to determine satisfactorily, because the umping of the overlying Fort Hays member on narrow divides nd isolated hills makes the location of its true upper boundary ncertain, but in sec. 29, T. 11 S., R. 16 W., in Ellis county, 5 miles est of Russell county, it is about 215 feet thick.

Upper sandstone division. The upper 20 to 25 feet of this member Russell county is a "salt and pepper" gray, rather soft, massive, ne-grained argillaceous sandstone, which in its lower part, to the outhwest, in Ellis county, becomes a finely gritty, fissile clay shale, ontaining one-inch beds of soft, very thin bedded sandstone. The ock is friable but not highly porous, and although its content of lime is so low as to be negligible, its content of clayey material is high. The grains range in diameter from 0.4 millimeters down to that of particles of fine clay. There is no great predominance of any one size, but the diameter of the larger particles averages about 0.125 millimeters. The grains are not much rounded and the largest ones are commonly much more angular than those of the intermediate sizes, an unusual feature. Most of the grains are quartz, chiefly colorless, a few of which show shadowy extinction under crossed nicols, but some are smoky gray and translucent and a few are pink and transparent. Dark gray chert, somewhat kaolinized orthoclase, and some black opaque fragments are rather common, and grains of clear orthoclase and some plagioclase (more calcic than An 30), faintly pinkish microcline, and perfect crystals of zircon showing no effects of abrasion are present. Much of the quartz shows abundant inclusions that are in part at least acicular crystals of brown tourmaline and apatite. This bed of sandstone is noteworthy in that it is immediately overlain by chalk and that it is the only thick bed of sandstone in the Cretaceous sections of Kansas above the Dakota sandstone, for at very few horizons above the lower part of the Graneros shale are the sediments even slightly sandy. A sandy unit at the top of the Carlile shale in South Dakota, Colorado and Wyoming,[6] the "Pugnellus" sandstone [7] in south-central Colorado, and the "Niobenton" sandstone [8] of the oil geologists in north-central Colorado, are comparable in lithology and stratigraphic position with and may be correlatives of this bed of sandstone in Kansas.

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[4] Gilbert, G. K.; The underground waters of the Arkansas Valley in eastern Colorado: S. Geol. Survey, 17th Ann. Rept. pt. 2, p. 565; 1896.

[5] Lindgren, Waldemar; Tests for gold and silver in shales from western Kansas: U. S. eol. Survey Bull. 202, pp. 5-19; 1902.

Lower shale and concretion division. The 190 feet or so of the Blue Hill member that lies below the upper sandy deposit is a uniformly gritless, noncalcareous, fissile, dark bluish-gray clay shale. It contains, especially in the lower part, scattered crystals and vertical veins of selenite one-eighth inch thick and some transparent barite. Some white, readily soluble salt ("alkali") stains the surface of the lower shale beds over small, poorly drained areas. Numerous concretions occur along definite bedding planes throughout these beds, and all those in any individual layer appear to be uniform in character. These beds of shale are very fissile, and where omewhat cracked by weathering they may properly be called paper shales.” This fissility and the accompanying minute joints ake this member somewhat open-textured, at least near the outcrop.

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[6] Darton, N. H.; Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range: Geol. Soc. America Bull. vol. 15, pp. 444-6; 1904.

[7] Stanton, T. W.; The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, p. 28, 1893.

[8] Henderson, Junius; The foothills formations of north-central Colorado: Colo. Geol. Survey Bull. 19, p. 85, 1920.
Ball, Max W.; Gas near Fort Collins, Colorado: Bull. Am. Assoc. Petro. Geol., vol. 8, p. 83; 1924.

For 120 to 150 feet below the sandstone bed the concretions are rge, ellipsoidal and septarian, and are composed of argillaceous lcium carbonate. Their diameter parallel to the bedding of the ale ranges from about 2 feet for the concretions in the lower part the member to 4 feet or more for those near its top. They are dely circular in plan, and their vertical is about half their hori- ntal diameter. They are composed of finely crystalline to dense lcite, which on fresh surfaces is generally dark gray, but weathers ghter. The larger weathered concretions develop a pseudogranular xture, formed by a series of nodular radiating cylinders about an ghth of an inch in diameter. Veins of brown to colorless coarsely ystalline calcite,[9] from a quarter of an inch to an inch thick, fill ints in nearly all the concretions in this unit, but are most notice- le in those in the upper part. The distribution of the concretions, ough more or less restricted to definite bedding planes throughout, comes increasingly random upward, the largest, found near the p, being very irregularly spaced.

A group of concretions whose top is 25 to 40 feet below the base the Niobrara formation is commonly very conspicuous, though varies greatly in total thickness and detailed characteristics. Two yers of large, bright tan concretions, identical with the rest except the color of the weathered surface, are notably persistent. The per and generally the more prominent of these is about 100 feet low the Niobrara; the other, which is about 35 feet lower, is the west concretion zone recognized in this middle unit.

The basal 65 feet of the Blue Hill member contains but two rsistent layers of concretions. Both layers are readily distinguish- le from those in the upper zones, for the concretions are smaller, tter, and contain more fossils. The upper concretions occur undantly on a bedding plane 47 to 50 feet above the base of the mber. They are commonly from 6 to 12 inches in greatest diam- r, elliptical in plan, and about 2 inches thick. On fresh surfaces ey are dark gray, but upon weathering they become brown.

The lower layer of concretions, which lies about 31 feet above the se of the member and averages about an inch in thickness, might called a persistent concretionary bed of ironstone or partly oxidized siderite. The concretions in this layer, which are similar in shape to those in the layer next above, are so abundant that they merge into one another. They contain but little lime, and only the thicker nodules show an unweathered center of blue-black siderite, the bulk of the bed being a hard, dense, somewhat clayey limonite concentrically banded with some hematite.

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[9] Erasmus Haworth, formerly director of the Kansas Geological Survey, orally mentioned the writers the fact that barite and strontianite accompany the calcite crystals in some hese veins.

Fossils. No fossils were found in the upper three-fourths of the Blue Hill member, but other investigators have found at places near by a rather extensive, chiefly invertebrate fauna in the septarian concretions.[1]

The lower 50 feet of the member is, however, more uniformly fossiliferous. The concretions 50 feet above the base contain a few small gastropods and a large pointed-shelled *Inoceramus* related to if not identical with *Inoceramus fragilis* Hall and Meek; the ironstone concretions contain the small finely ribbed ammonite *Prionocyclus wyomingensis* Meek, the original nacreous luster of which is preserved in a number of the specimens; and the fine-ribbed *Inoceramus fragilis* of normal size. A few feet above the base thick *Inoceramus* shells occur, and at the very base of the member there is an accumulation of sharks' teeth (both the cutting and the crushing types), fragments of fish bones (largely centra of the vertebræ), and phosphatic reptilian coprolites.[2]

Topographic expression. The beds of the Blue Hill shale member are so slightly resistant to erosion that they form prominent topographic features only where they are capped by harder rock. The Fort Hays limestone member commonly forms such a capping, and the resulting flat-topped buttes and spurs, which stand high above their surroundings, have been noted in the description of the Fort Hays limestone member. The concretions in the middle and lower part of the member give rise to less prominent hills, the large, scattered concretions forming more or less conical buttes and the ironstone bed a low but very persistent flat-topped bench. In and near the northwest corner of Russell county a conspicuous terrace covered with younger gravels occurs for several miles at a nearly constant stratigraphic horizon about 80 feet below the top of the member.

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[1] Mudge, B. F.; Notes on the Cretaceous and Tertiary periods of Kansas: U. S. Geo and Geog. Survey Terr. Bull., vol. 2, p. 219; 1876.

Cragin, F. W.; On the stratigraphy of the Platte series: Colorado Coll. Studies, vol. p. 50; 1896.

Logan, W. N.; The Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. p. 219; 1897.

Logan, W. N.; Some additions to the Cretaceous invertebrates of Kansas: Kansas Univ Quart., vol. 8, pp. 87-98, pls. 20-23; 1899.

Logan, W. N.; A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geology, vol. 7, pp. 88-99; 1899.

[2] These determinations were made in the field by J. B. Reeside, Jr.

Soil and vegetation. The soil on the outcrops of the Blue Hill
ember is generally thin and is entirely absent from many of the
eeper slopes, but it is fairly thick on the relatively flat uplands.
he face of the terrace for about 20 or 25 feet below the ironstone
ench is almost everywhere barren. Near the southeastern margin
its outcrop the member caps broad divides, on which it forms a
ack soil. Vegetation grows rather sparingly on the member, the
aracteristic coarse grasses being accompanied by small shrubs on
e sandy unit and by a few yucca plants in places on the zones of
rger concretions. The clay shales are commonly wet a foot or so
ck from the exposure, and an almost unbroken line of small seeps
water at the very base of the member supports a strip of ranker
getation.

Means of recognition. The rocks of the Blue Hill member could
confused only with those of the Graneros shale, for all the other
ay, gritless Cretaceous shales of central Kansas effervesce readily
der hydrochloric acid. The presence of large calcareous concre-
ns, the absence of an underlying series of sandstone and varie-
ted shale, and the much greater thickness of the Blue Hill (215 as
ainst 40 feet), readily distinguish it from the Graneros formation.

The boundary between the Blue Hill shale and the chalky Fort
ays limestone is at most places easily recognizable, for there is
confusing transition zone, clay shales are not found in the Fort
ays, and beds of chalk are not found in the Blue Hill. The upper
nit of the sandy unit coincides with the base of the soft or hard
alk, and on clean exposures this contact is unmistakable. Where
is covered, the topography and the soil are generally reliable cri-
ria by which to identify the boundary, the more or less conspicuous
nch of white chalky soil almost everywhere marking the lower
dge of the Fort Hays, and the dark, sodded or bare slope of the
ue Hill member below showing a pronounced bluish-gray cast and
ing studded with large concretions. The Blue Hill member is not
hard and is more plastic than the Fort Hays, and these facts and
e sandstone bed at the top of the Blue Hill should make the con-
ct recognizable in all carefully taken records of drill holes.

Horizons suitable for mapping. As already noted, the widespread
mping of the Fort Hays member makes the contact of the Fort
ays and the Blue Hill member a key horizon that can be used suc-
ssfully for detailed mapping only with the exercise of great care.
e persistence, thinness and characteristic lithology of the iron-
ne bed near the base of the Blue Hill make it an excellent key

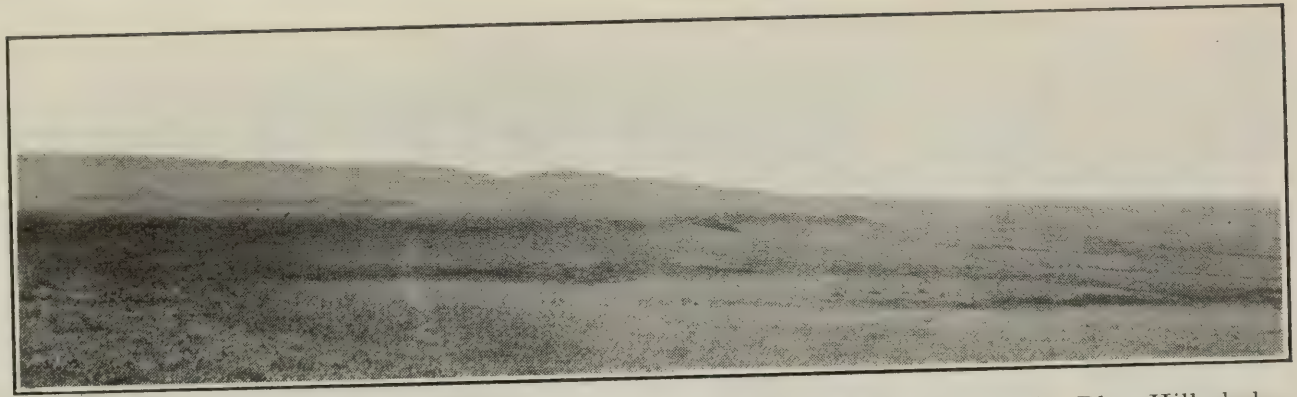
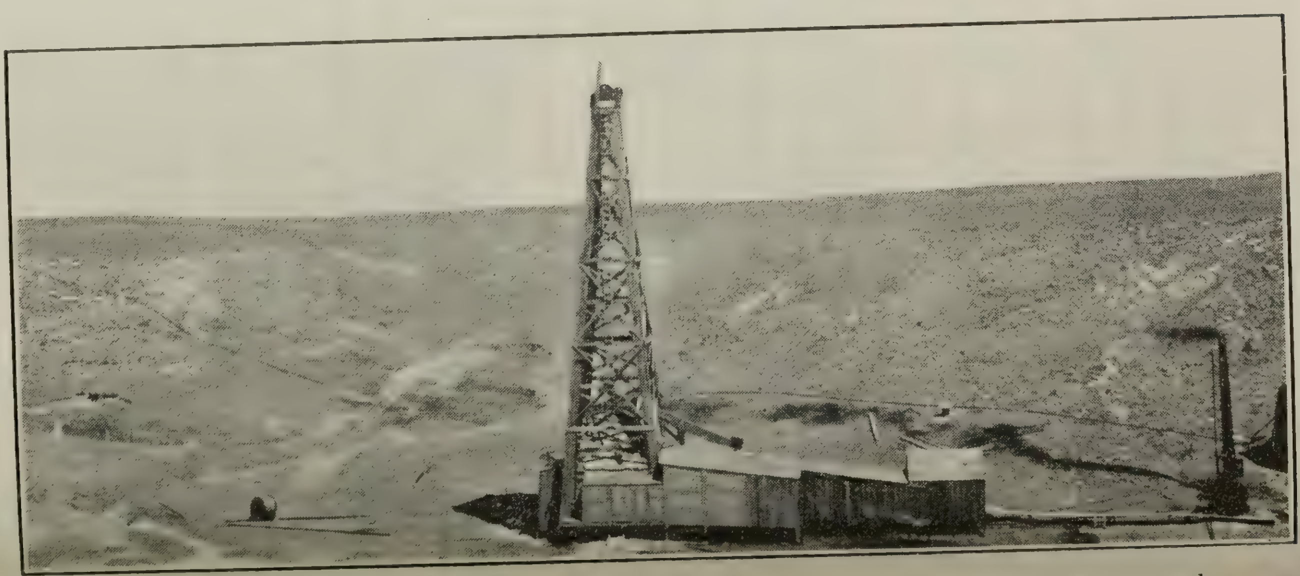


FIG. 4. A prominent bench capped by ironstone concretions in basal part of the Blue Hill shale member of the Carlile shale, in sec. 3, T. 11 S., R. 15 W., Russell county.



member of the Greenhorn limestone, shown as ed. The less closely spaced, flat calcareous concretions about 50 eet above the base of the member may also be used for this purpose, ut they are somewhat less satisfactory than the ironstone bed. The igher concretions, because of their greater size and weight, tend to lide down the steeper slopes, making it difficult to determine their rue stratigraphic position. The two lines of rusty-weathering conretions near the middle of the member are the most distinctive of he horizons of concretions and can be used if care is taken to find he highest individual concretions.

Name. The Blue Hill member was named by Cragin,[3] in 1896, he "Victoria clays," from the town of Victoria, and Victoria creek ear by, in Ellis county, Kansas, six miles west of Russell county. n the following year Logan[4] called this member the Blue Hill shales, pparently from the Blue Hills, in Mitchell county, Kansas, which e stated "rest upon the Ostrea beds and are composed of the Blue ill shale, capped by a layer of Fort Hays limestone." Logan's nit was limited below by his "Ostrea shales" (the Fairport chalky hale member of this report) and above by the Septaria horizon—he large septarian concretions in the upper part of the present Blue ill member. The Septaria horizon he included in the Niobrara, alhough he stated that it is at many places embedded in the Blue ill shale. Not only are the shale beds in and above the Septaria f Logan lithologically indistinguishable from those of his Blue Hill, ut the diagnostic septarian concretions in and near Russell county xtend much lower into his Blue Hill member than Logan suspected, nd the fossils are Carlile and not Niobrara species.[5] Most later riters, including Logan,[6] have included the Septaria horizon in the lue Hill, and it is here included in that member. Cragin described s the "Cannonball zone" a group of large concretions in the lower art of his "Victoria clays," apparently applying the term to the wer of the two brown-weathering concretion layers. Although ragin's name "Victoria" has slight priority over Logan's name lue Hill, and about equal usage with Blue Hill, it conflicts with ree other uses of Victoria (for rocks of Devonian, Mississippian nd Cretaceous ages) in American and Canadian literature, but ere is no conflict with the name Blue Hill. For this reason Blue

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[3] Cragin, F. W.; On the stratigraphy of the Platte series: Colo. Coll. Studies, vol. 6, 50; 1896.

[4] Logan, W. N.; The Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, . 218-219, 225; 1897.

[5] J. B. Reeside, Jr.; personal communication.

[6] Logan, W. N.; The invertebrates of the Benton, Niobrara and Fort Pierre groups: ansas Univ. Geol. Survey, vol. 4, pp. 434-436, 441; 1898.

———; A discussion and correlation of certain subdivisions of the Colorado formation: ur. Geology, vol. 7, pp. 88-89; 1899.

Hill has been adopted for this member and the name "Victoria" has been discontinued. The fauna found in the Blue Hill member is an upper Carlile assemblage of species.[7]

FAIRPORT CHALKY SHALE MEMBER.

Character and distribution. The Blue Hill member is underlain by 85 feet of chalky marl and thin chalk beds that are here called the Fairport chalky shale member of the Carlile shale. Although this member crops out in its entire thickness only in the northwestern eighth of Russell county, its lower part is exposed on the uplands throughout the area. Its basal third or fourth contains nearly all the harder chalk of the Fairport member, the upper beds being composed almost entirely of chalky marl.

So persistent laterally in and near Russell county are even the thinnest beds of the Fairport member that the accompanying composite section is thought to be representative for the area. Minor variations in the thickness of the several beds and units, but no general directions of thickening were found, and the variations are in fact less than the probable error in measurement.

Average section of Fairport chalky shale member of the Carlile shale near Fairport, Russell county, Kansas (in descending order).

[Fossils identified by J. B. Reeside, Jr.]

	Ft.	In.
Blue Hill shale member of Carlile shale	..	..
Fairport chalky shale member of Carlile shale:		
1. Chalky, slightly sandy shale; dark where fresh; weathers yellow. Abundant fragments of thick shells of *Inoceramus* and some *Ostrea congesta*	11	0
2. Chalky, slightly sandy shale with one or more half-inch beds of medium gray, hard, crystalline limestone at top. Finely banded; weathers yellow; selenite crystals on surface. Very large, thin shells of *Inoceramus* near base	13	0
3. Sandy chalk, rusty brown, soft. *Inoceramus* (resembles *I. dimidius*), *Prionotropis woolgari, Scaphites,* fragments of teeth and bone	..	3
4. Chalky shale, very dark gray with half-inch bed of bluish-white clay near center. Contains *Ostrea*	2	2
5. Ocherous clay	..	2
6. Chalky shale	..	2
7. Sandy chalk, brown streaked with gray. Contains *Prionotropis woolgari* and *Serpula*	..	5
8. Chalky shale with beds of white clay one-eighth inch thick. Very large, very thin shells of *Inoceramus*	1	10
9. Argillaceous chalk, brown. No *Inoceramus* shells	..	2
10. Chalky shale with half-inch bed of clay at top	1	11
11. Argillaceous chalk, brown. No *Inoceramus* shells	..	2
12. Chalky shale	3	0

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[7] Reeside, J. B., Jr.; personal communication.

Sandy chalk, concretionary, ferruginous, soft. Abundant fragments of thick *Inoceramus* shells	..	3
Chalky shale	2	5
Sandy chalk, concretionary, ferruginous. Large, very thin shells of *Inoceramus*	..	3
Chalky shale with thin beds of yellow clay. Contains *Ostrea*	6	3
Sandy chalk, hard. Contains many fragments of *Ostrea*, *Inoceramus* and *Serpula*	..	2
Chalky shale, white and buff mottled, with thin yellow clay at top. Contains smooth, white *Ostrea*	4	2
Agrillaceous sandy chalk; tan, thin-bedded	..	2
Chalkv shale	1	4
Argillaceous, sandy chalk; hard, tan, thin-bedded	..	2
Chalky, sandy shale, medium gray to drab where fresh, mottled white and buff where weathered; thin-bedded. Fragments of thick *Inoceramus* shells; abundant *Ostrea congesta*	11	3
Slightly sandy chalk, rusty brown, fossiliferous	..	4
Chalky shale, tan, with abundant *Ostrea congesta*	2	0
Chalk, tan; contains a few fish scales	..	3
Chalky shale, very slightly sandy; black where fresh, very light gray to tan where weathered. Contains abundant *Ostrea congesta*	2	3
Chalk, hard, brown to pink (the Pink lime of some oil geologists)	..	4
Chalky shale, tan, fissile. Fish scales and abundant *Ostrea congesta*	5	2
Chalk, rather coarse grained, dark gray to buff. Contains *Inoceramus fragilis* and *Priontropis woolgari*	..	5
Chalky shale, dark to white and tan mottled; fissile. Contains two horizons of concretions, the upper random and discontinuous, about 5 inches thick and less than 2 feet below top; the lower closely spaced, persistent; concretions ellipsoidal, about 8 inches thick, and about 3 feet below top. Many fish scales, *Inoceramus fragilis*, and *Prionotropis woolgari*	7	11
Chalk, hard, gray. Contains *Inoceramus fragilis* and *Prionotropis woolgari*	..	5
Clay, ocherous in color, highly calcareous; resembles bentonite	..	5
Chalky shale, slightly sandy, fissile; medium gray where fresh, buff or tan where weathered; includes three horizons of concretionary, harder, crinkly bedded chalk in beds about 2 inches thick. Contains fish scales and *Ostrea*	4	10
eenhorn limestone	..	..
Total thickness of Fairport member	85	0

Distinctive beds. The thin but persistent beds of yellow and white y are valuable aids in identifying the adjacent chalk beds. They e easily recognizable by a peculiar jointing that has been approiately likened to the texture of fish meat. The distinctive 5-inch d of yellow clay near the base of the member (bed No. 32 of the companying section) is a means of identifying the overlying chalk d as the one 5½ feet above the top of the Greenhorn limestone. e persistence and the structure of these beds of clay greatly resemble that of the layers of bentonite[8] which are so common in the Cretaceous sediments of Wyoming and elsewhere. The clays in Russell county, however, do not show the marked peculiarity of most bentonites—that of swelling to several times their original volume when immersed in water—and so, though they may be bentonitic, many geologists would not call them true bentonites.

The distinctive ellipsoidal calcareous concretions that lie about 11 feet above the base of the member (the lower of the two zones of concretions in No. 30 of the accompanying section) range from a foot to a foot and a half in diameter and from 6 to 10 inches in thickness and occur regularly every few feet horizontally in all the exposures examined. In many of the exposures the median plane carries abundant large *Inoceramus* shells. The bedding of the chalky shale bends sharply over and under the concretions (Fig. 3). The three horizons of much flatter concretions at the base of the member (No. 33 of section) are also distinctive.

An extreme example of the variation found in this member is seen in the bed of chalk that lies about 20 feet above its base—the Pink lime of some oil geologists (No. 27 of section). About 2 miles south of Fairport this bed is a hard, pink chalk about 6 inches thick, but a few miles to the northwest it becomes soft, rusty brown, and but 2 or 3 inches thick, and 3 miles north of Wilson it is a limestone or chalk breccia consisting of scattered, slightly tilted flat fragments of pink, dense limestone, from 2 to 8 inches across, embedded in porous gray chalk.

The chalky shale beds are dark gray, dark buffy gray, or nearly black on fresh exposures, but where weathered are light tan. The beds in the upper third of the member (Nos. 1 and 2 of the section) weather to a brighter yellow than those below.

Fossils.[9] Flattened shells of *Ostrea congesta* about half an inch in diameter abound throughout the member, occurring chiefly in the shale, but also in the chalk, both isolated and in clusters on clam shells. The ammonite *Prionotropis woolgari* occurs most abundantly in the lower 15 feet and about 20 feet below the top. Traces of the worm *Serpula tenuicarinata* Meek and Hayden were found in two of the upper chalk beds. A deeply cupped, coarsely ribbed *Inoceramus*, similar to but not identical with *Inoceramus dimidius*, less than an inch in diameter, occurs in a few beds about 25 feet below the top of the member. *Inoceramus* shells, many of them less than a quarter of an inch thick, but some measuring 32 inches or nore across, are abundant from 20 to 45 feet below the top. Shells of this type are rarely found unbroken and generally are seen merely as cross sections of broken shells. Fragments of thick *Inoceramus* shells occur most abundantly in the upper beds, but are also found n the middle portion of the member. Fish scales, some of them an nch across, are commonest in the lower fourth, but some, which are associated with fragments of teeth, extend nearly to the top, though n fewer numbers. Near the west quarter corner of sec. 5, T. 13 S., R. 15 W., Russell county, lentils of brown lignite a foot or more ong, containing thin layers of "glance" coal, occur at the base of a concretionary chalk bed 3 feet above the base of the member.

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[8] Bentonite is probably a decomposed volcanic ash. See Hewett, D. F.; The origin of bentonite [etc.]: Wash. Acad. Sci. Jour., vol. 7, pp. 196-198; 1917.

[9] Identifications by J. B. Reeside, Jr.

Means of recognition. Only the lower 20 or 25 feet of the Fairport member is hard enough to make conspicuous topographic features. This part makes benched slopes or small points and isolated ills on top of the persistent bench formed by the Greenhorn limestone. The middle and upper parts of the member make nearly flat weathered slopes with few exposures.

The soils derived from the lower and middle parts of the Fairport member are dark drab to black; those derived from beds near the op are sandy and bright yellow. The high fertility of these soils nd the gentleness of the slopes on which they lie combine to make hem some of the most desirable wheat-growing land in the region. Where the soils formed by this member are not under cultivation hey bear an abundant growth of native short grasses.

The Fairport member somewhat resembles the Smoky Hill and ort Hays members of the Niobrara formation and the Greenhorn mestone. From the Fort Hays member and from most of the Greenorn limestone it can be readily distinguished by the facts that it oes not contain numerous hard chalk beds, that its weathered color s yellower, and that it is underlain by a series of beds of chalk and halky shale. It can be distinguished from the Greenhorn limestone y means of features mentioned in the description of that formation, nd it can be distinguished from the Smoky Hill member by its ack of massive beds of chalk and large ferruginous concretions and s abundant content of shells of *Ostrea*.

The boundary between the Fairport and Blue Hill members of he Carlile shale is readily determinable. The beds below the contact effervesce with acid and weather to light yellowish tints; those above the contact are free from lime and are dark bluish gray. The igh degree of fissility and the concretions and the ironstone bench in the Blue Hill, as well as the slight sandiness and bright yellow color of the upper part of the Fairport, afford additional means of recognizing this boundary. The striking change in the composition and stickiness of the shales at the upper limit of the member should be detectable in drilled holes, although few well logs show this change.

Beds useful in detailed mapping. The beds that form the lower 25 feet of this member are useful for detailed mapping, for they are distinctive and easily followed. With greater care, the chalk beds in the middle and upper parts can also be traced, but the poor exposures common to this part of the section make it generally less desirable for use than the easily recognized beds in the lower part of the overlying Blue Hill shale. Although the contact of the Blue Hill shale with the Fairport member cannot be followed as continuously as many of the hard beds, it is sufficiently distinctive to be mapped. The wide, soil-covered flat uplands that are underlain by the lower part of this member may most profitably be mapped by the use of numerous shallow drill holes. The sequence of the beds, which is especially distinctive in the lower 25 feet of the member, should make the recognition of key horizons in such borings possible.

Name and correlation. The name Fairport is here proposed for this member, from the exposures a few miles south and west of Fairport, Russell county. The lower 22 feet of the member are well exposed in the southeast quarter of sec. 7, T. 12 S., R. 15 W., Russell county, 2 miles south of Fairport. Good exposures of the lower 55 feet are found in Ellis county, in the southeast quarter of sec. 3, T. 12 S., R. 16 W., 2½ miles southwest of Fairport; of the lower 60 feet in the northeast quarter of sec. 29, T. 12 S., R. 16 W., 5 miles west of Fairport; and of the upper 28 feet in the southwest quarter of the same section. The name is proposed as a geographic name to replace Logan's "Ostrea shales," a term which he first used in 1897,[1] and which has been adopted by subsequent writers. Logan somewhat ambiguously defines the lower limit of his "Ostrea shales" by stating that the "Fence-post horizon" is "near the top of the (underlying) limestone group" (p. 217), but this ambiguity is cleared up by his statement that the "Ostrea shales rest conformably upon the Fence-post horizon of the lower group" (p. 217). His name was distinctive and appropriate, for the shales contain an abundance of *Ostrea*, but modern American stratigraphic names are geographic, taken from places where typical exposures are found.

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[1] Logan, W. N.; The Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 217, 218; 1897.

The fossils contained in the Fairport member are the species found in the lower part of the Carlile shale of Colorado, Wyoming and elsewhere.[2]

GREENHORN LIMESTONE.

Below the Carlile shale lie about 100 feet of beds of hard chalk and chalky marl, which constitute the Greenhorn limestone. This ormation crops out on both sides of the valleys of the tributaries of he three large streams that run eastward across Russell county—Smoky Hill and Saline rivers and Wolf creek. Hard chalk in beds ess than a foot thick alternate with chalky shale in the upper hree-fourths of the formation. The proportion of chalk to marl is ighest about one-fourth way down from the top. The lower fourth f the formation contains, in addition to the chalk and chalky hale, thin beds of hard crystalline limestone. From several measurements it seems that the thickness of the Greenhorn formation decreases from 105 or 110 feet in the northern part of Russell ounty south-southeastward to 85 or 90 feet in the southern part. The great abundance of the fossil *Inoceramus labiatus*, the stratiraphic position, and the calcareous composition of the formation ermits a close correlation of the formation[3] with the Greenhorn imestone of parts of Colorado, Wyoming and elsewhere. The name Greenhorn was given by Gilbert,[4] in 1896, to corresponding beds in outhern Colorado, which are typically exposed at Greenhorn station nd on Greenhorn creek, south of Pueblo, Colo. The formation in Russell county, Kansas, is divisible into four members, here listed n descending order: (1) An upper unnamed member consisting of eds of chalky shale and fossiliferous chalk; (2) the Jetmore chalk member, which consists of regularly alternating beds of chalk and halky shale; (3) an unnamed member of chalky shale containing ew beds of chalk; and (4) the Lincoln limestone member, consisting of thin beds of crystalline limestone in a series of beds of chalk nd chalky shale.

Upper member. The upper 20 feet of the Greenhorn limestone in Russell county is a chalky shale containing three beds of chalk, 4 o 10 inches thick. The uppermost one—the top bed of the member nd of the formation—is the justly famous "fence-post limestone" r "post rock" of the farmers of western Kansas. It is a rather ard, slightly sandy, fairly coarse but even-grained and massive chalk that maintains a thickness of 8 or 9 inches. Where it lies under cover it is softer. On fresh surfaces the rock is dark gray, but it weathers to a light yellow gray or cream and shows a prominent rusty median line. It contains relatively few fossils. The rock, which is nearly free from joints, is easily split with wedges to desired shapes, and so it is widely used as building stone, bridge masonry, fence posts, and even telephone poles throughout the Greenhorn area in western Kansas; in fact, in this nearly treeless region wooden posts are rarely seen, and at nearly every outcrop of this bed in Russell county the rock has been quarried to some extent for these uses.

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[2] J. B. Reeside, Jr.; personal communication.

[3] J. B. Reeside, Jr.; personal communication.

[4] Gilbert, G. K.; The underground waters of the Arkansas Valley in eastern Colorado: S. Geol. Survey, Seventeenth Ann. Rept., pt. 2, p. 564; 1896.

The 8 or 9 feet of soft, chalky, slightly gritty shale below the "fence-post limestone" contains several layers of thin, flat, rather inconspicuous concretions. Beneath these beds of marl lies a layer of hard, iron-stained chalk, 5 inches thick, which contains many *Inoceramus* shells. Below the middle chalk lies 5 feet of chalky shale, which is in turn underlain by a zone 2½ feet thick of thin, highly fossiliferous concretionary chalk beds. In the southeast quarter of sec. 25, T. 15 S., R. 17 W., Ellis county, an elongate chalk concretion with a coarsely crystalline core of barite a few inches in diameter and several feet long was found at this horizon. The basal 4 feet of the member is chalky shale. Analysis of a sample of the marl shows that about 55 per cent of it by weight is insoluble silty material containing small flakes of muscovite. The thickness of this member in Russell county is nearly constant. Apparently it increases southward from 19 to 21 feet.

Jetmore chalk member. The group of alternating thin beds of chalk and chalky shale that occupy the interval from 20 to 40 feet below the top of the Greenhorn formation is the Jetmore chalk member. The uppermost bed of this group—the "*Inoceramus* limestone" or "shell bed" of oil geologists—is a hard, thin-bedded to massive, very fossiliferous fine-grained chalky limestone, which within narrow limits of variation is about a foot thick. It is a light buff gray on fresh exposures, but weathers almost white. A bed of flat, chalky concretions occurs in the shale about 2 feet below the top of the member. Below its upper bed the Jetmore member is an alternating series of layers of chalk and chalky shale, the layers of chalk decreasing downward in thickness from 6 inches to 1 inch, and the marl beds from about 2 feet to 2 inches. The upper 10 feet or so contain the most fossils, which are found in greatest abundance in the 1-foot bed at the top of the member. The base of the Jetmore nember is not sharply defined, for by a progressive thinning of the ower chalk beds it grades into the underlying chalky shale. Clean xposures, such as those in secs. 17 and 20, T. 13 S., R. 14 W., ussell county, show that 12 or 15 layers of chalk more than 3 nches thick are contained in the upper 20 feet, but that thinner eds extend a few feet lower.

Unnamed member. Below the Jetmore chalk lies an unnamed ember consisting of about 35 feet of chalky shale that contains a ew thin beds of chalk and clay. A rough quantitative analysis inicates that a sample of this marl included 65 to 70 per cent of silty aterial which contained a few small flakes of muscovite. Perhaps e most prominent and most easily recognizable part of the member a five-inch massive bed of hard medium-gray fine-grained chalk, hich lies 14 or 15 feet above the base of the member and contains ell-preserved *Inoceramus* shells, and flat vertical marks resembling lades of grass. Below this bed lies 1 or 2 feet of yellow or light luish gray clay and some gray and green chalky shale, which overlie softer, lighter colored, less fossiliferous bed of chalk of about the me thickness. Above the fossiliferous stratum lies a 2-foot or -foot bed of chalky shale, which is succeeded above by thin, slightly ndy, beds of chalk containing small pyritic nodules, and a few ds of yellow clay. This member thickens from 28 feet in the rthern part of Russell county to about 40 feet in its southern part.

Lincoln limestone member. The lowermost subdivision of the reenhorn limestone is here called the Lincoln limestone member. consists of beds of chalk and chalky shale, with thin beds of hard ark gray crystalline slightly sandy fossiliferous limestone at s base and top and in some places near the middle. The limestones nit a strong odor of petroleum on fresh fracture. A few thin beds yellow clay occur in the lower half of the member. The beds of ystalline limestone are commonly only 2 to 6 inches thick and are assive within this thickness. Under the microscope the rock is en to be composed largely of fibers derived from the prismatic yer of *Inoceramus* shells, with lesser amounts of spherical foramifera, and a few brown, probably phosphatic granules, the whole bedded in a matrix of finely crystalline calcite. Although dark ay on fresh surfaces these beds are greenish or brownish gray here somewhat weathered. The Lincoln member ranges in thickss from 20 feet in the western part of the county to about 25 et in its eastern part.

Distinctive colors of the members. The marly beds of the Greenhorn limestone are dark gray where fresh, but become light, more or less yellowish gray on weathering. The members apparently contain different quantities of iron, for on weathering each develops a distinctive shade of yellow. The Jetmore chalk is the lightest colored member of the formation, its beds becoming a very pale, faintly creamy gray or near-white. The Lincoln member appears to be the most ferruginous, for where weathered it is a rather bright tan. The members above the Jetmore and the Lincoln assume intermediate colors, the one at the top of the formation being lightest, but both are a rich cream color.

Fossils.[5] The Greenhorn limestone contains an abundance of shells of *Inoceramus labiatus* Schlotheim—flat, elongated, tongue-shaped bivalve shells, commonly about 6 inches long, that are ornamented by concentric rounded ribs which themselves bear finer ribs. This fossil is most abundant in the lower part of the upper member and in the top layer of the Jetmore chalk, and although it occurs throughout the formation, it was not found beyond its limits. Other large fossils are not common in this formation, but a few other interesting species occur sparingly: *Baculites gracilis* Shumard, *Metoicoceras whitei* Hyatt, *Helicoceras pariense* (White), a second species like *Helicoceras corrugatum* Stanton, and a new species of the ammonite genus *Puzosia*. There are also scattered oysters much like *Ostrea congesta* Conrad, worm-eaten pieces of wood,[6] small fragments of teeth, scales and bones, and possible plant stems in the lower part. The surfaces of many of the chalk beds show nearly microscopic *Globigerina*, and these minute fossils make up probably one-fourth of the volume of the samples of chalky shale examined.

Topographic expression. The Greenhorn limestone is second only to the Fort Hays member of the Niobrara formation in topographic prominence, the thick series of relatively hard chalk beds nearly everywhere forming a steep benched slope or actual bluff. The Jetmore member makes the most conspicuous and persistent scarp, its topmost bed capping a steep slope, 10 to 20 feet high, at all but the very poorest exposures. The "fence-post limestone," at the top of the upper member, also makes a persistent bench, but as the underlying 20 feet is chiefly soft chalky shale, the slope capped by this bed is gentle, no conspicuous bluff being formed. The thin-bedded crystalline limestone at the top of the Lincoln member commonly forms a minor bench on the faces of the steep slopes of the Greenhorn limestone in the larger valley, and at some places where the slopes are gentler it makes a scarp distinct from that formed by the upper members, and traceable for a mile or more. At many places the similar strata at the base of the Lincoln and other chalk beds here and there throughout the formation form minor benches.

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[5] Identifications by J. B. Reeside, Jr.

[6] Apparently coniferous, according to F. H. Knowlton.

Soil and vegetation. Owing perhaps chiefly to the steepness of the slopes, the soil on the outcrops of the Greenhorn limestone is commonly thin. On the gentler south slopes of the divides, however, the soil may be sufficiently thick to mask all but the most prominent hard beds. Throughout most of the county the Jetmore bluff is either quite barren or is covered with a nearly white, thin, chalky loam, but the other members permit the accumulation of a thicker soil. Tall, coarse, native grasses are the commonest growths on the formation, but on a few of its more sheltered cliffs the Jetmore member supports clumps of small conifers.

Resemblance to other Cretaceous strata. The Greenhorn limestone resembles in its chalkiness the Smoky Hill and Fort Hays members of the Niobrara formation and the Fairport member of the Carlile shale. Its beds of chalk are thicker and more numerous and its weathered exposures are less stained with yellow than those in the Fairport member. It differs from the Fort Hays and Smoky Hill members chiefly in containing no thick, massive beds of chalk and in its inclusion, near the base, of thin beds of crystalline limestone. It further differs from the Fort Hays member in containing much interlaminated marl.

The contact of the Greenhorn limestone with the overlying Carlile shale is rather arbitrarily drawn at the top of the "fence-post limestone." No real lithologic distinction can be made between the lower 25 feet of the Fairport chalky shale member and the uppermost member of the Greenhorn limestone. In fact, the unit containing flat chalk concretions extends from about 22 below to 12 feet above this boundary. The paleontologic change, however, is fairly distinct. *Inoceramus labiatus* occurs only below the boundary and *Inoceramus fragilis* and *Prionotropis woolgari* only above it, and no zone of admixture of faunas was noted. Fortunately, this paleontologic change occurs at the top of an easily recognizable stratum, the "fence-post limestone." Distinctive sequences of chalk, chalky concretions, yellow clay, and chalky shale make the horizon easily determinable where the overlying rocks are exposed; and the characteristics of the individual chalk beds in the two members below the contact aid in determining the position of the boundary where the underlying beds are exposed. In addition, the widespread quarrying of the "fence-post limestone" is in itself a valuable aid in the recognition of that bed, but it must be employed with care, for at some places the chalk bed 5½ feet above the "fence-post limestone," and at a few places other chalk beds above and below, have been similarly quarried. The gentle slope on the Fairport member is commonly farmed down to the chalk beds in the lower 25 feet of the member. From that point to the base of the Fairport member short grasses generally grow, but at the "fence-post limestone" there is a sharp change to taller, coarser grasses. The nearly white persistent bluffs on the Jetmore member are easily distinguished from the discontinuous exposures of cream and reddish tan shales on the gentler slopes of the upper member of the Greenhorn limestone and the lower part of the Fairport member. The contact is one that is not at all likely to be noted in well logs.

Value for detailed mapping. The thin but hard, persistent and widely distributed beds of chalk in the Greenhorn limestone make that formation almost an ideal one for detailed structural mapping, and the work done by commercial geologists in and near Russell county has been virtually restricted to two layers of chalk in the upper 20 feet of the formation—the "fence-post" and the "*Inoceramus*" beds. Throughout much of the area lower beds also may be profitably employed, the prominent upper and basal layers of the Lincoln member being good key beds for detailed mapping. For reconnaissance work the top of the conspicuous Jetmore member is the most satisfactory horizon in the Cretaceous section of western Kansas.

Names of members. Logan[7] divided his lower limestone group (the Greenhorn and Graneros formations of this report) into five members. Four of these—the Lincoln, "flagstone," "*Inoceramus*" and "fence-post"—constitute the present Greenhorn limestone. Between the Lincoln member and the "fence-post bed" of the upper member, Logan's subdivisions are not recognizable in Russell county, though his "*Inoceramus* horizon" probably comprises the upper part of the Jetmore and the lower part of the upper member as delimited in this report.

Cragin[8] proposed the name "Downs limestone" for the "fence-post bed." Although this bed is unusually persistent for one so thin, it does not merit classification as a separate member, and its local ame, “fence-post limestone,” is widely known and quite satisfacory.

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[7] Logan, W. N.; The Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 215-217; 1897.

[8] Cragin, F. W.; On the stratigraphy of the Platte series or Upper Cretaceous of the Plains: Colo. Coll. Studies, vol. 6, p. 50; 1896.

The name Jetmore is proposed for the 20-foot member that lies rom 20 to 40 feet below the top of the Greenhorn limestone. It is aken from prominent exposures south and east of Jetmore, along the outh side of Buckner creek, in Hodgeman county, Kansas. Although ts base is indefinite in many places, the progressively varying alernation of chalk and chalky shale stamps this member as a definite nit of sedimentation. The usage among oil geologists of the term *Inoceramus* bed” for the top stratum of this member may lead to ome confusion, for Logan's “*Inoceramus* horizon” probably included halk layers above and below this bed, but its prominence and peristence make the upper bed of the member so valuable for structural napping that a name to emphasize its value is well deserved.

Lincoln “marble” was a local name applied to crystalline limetone quarried in Lincoln county, and was apparently first used in he literature as the name for a geologic unit by Cragin[9] in 1896. As a name for the quarried stone, *marble* is justified by usage, but a more precise lithologic term for the rock would be *crystalline limetone.*

GRANEROS SHALE.

The beds of clay shale that lie below the Greenhorn limestone and bove the Dakota sandstone constitute the Graneros shale. This ormation, which is about 40 feet thick, crops out as a continuous narrow band at the base of the Greenhorn bluffs along the larger streams in Russell county. It contains thin, hard, sandy layers, which are few and calcareous near the top and more abundant and highly ferruginous in the lower half. Irregular variations in the thickness of the formation of as much as 20 feet are due to the enticular form of the beds of sandstone at the base of the Graneros shale and top of the underlying Dakota sandstone.

Lithology. The soft, noncalcareous, gritless shale of this formaion is very fissile, and where naturally exposed is a dark bluish gray. In places the weathered slopes are strewn with crystals of selenite and stained rusty brown, and the minor joints are covered with a sulphur-yellow powder. The iron sulphate melanterite is abundant on the weathered outcrops, and its bitter taste is fairly characteristic of the formation.

Some one-inch beds of sandy limestone occur in the upper part of the Graneros shale. In the southwestern part of the county a thin-bedded, somewhat iron-stained bed of sandstone a few inches thick, which lies about 10 feet below the top of the formation, is strongly ripple-marked on its upper surface. These ripples are of the symmetric or oscillation type, and commonly have an amplitude of about a quarter of an inch and are 2 inches from crest to crest. They trend about S. 30° W. In some localities a white to yellow clay bed, slightly more than an inch thick, occurs about 2 feet below the top of the formation. At many places the lower half of the formation contains numerous beds of hard, ferruginous, gypseous sandstone, from 1 to 6 inches thick. These beds are discontinuous laterally, few of them being traceable more than 200 or 300 feet.

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[9] Cragin, F. W.; idem.

Local zones of calcareous concretions were found at two horizons. In the southeast part of the county the upper concretions are about 2½ feet below the top of the formation; they are fossiliferous and distort the bedding of the overlying shale for as much as a foot with slender nodular protuberances that extend into the upper beds. The lower concretions, which occur about 20 or 25 feet below the top, are also fossiliferous and are very argillaceous and sandy. In places they contain cone-in-cone layers less than half an inch thick.

Fossils.[1] Several of the harder beds in the upper part and a few in the lower part of the Graneros shale are fossiliferous. The small oysterlike shell, *Exogyra columbella* Meek, with curled beak and rather fine, low-rounded ribs, occurs in the lower half of the formation and is usually accompanied by the small pelecypods, *Callista tenuis* Hall and Meek and *Corbula nematophora* Meek. At a few places in the lower part of the formation the high-spired gastropod, *Turritella whitei* Stanton, and fragments of fish teeth, bone and scales were found at several horizons throughout the formation. In the upper part a medium-sized undescribed oyster occurs abundantly at some places accompanied by a large undescribed species of *Prionotropis,* also known in the upper or Belle Fourche shale member of the Graneros shale of the Black Hills region.

Exposures. The Graneros shale is soft and at many of its outcrops makes a gentle slope. In parts of the larger valleys the hard overlying Lincoln member of the Greenhorn limestone and the sandstone beds in the underlying Dakota formation make a steep bluff in which the Graneros shale is well exposed, but at such places talus and slides from the Greenhorn exposures obscure parts of it.

Distinguishing features. This formation resembles only the Blue Hill member of the Carlile shale and some beds in the Dakota sandstone. The dark fissile shales, with their persistent melanterite taste, are nowhere chalky, though in places they include thin, hard, calcareous layers. The occurrence of harder, sandy strata that are commonly ferruginous, the absence of abundant calcareous concretions, the thinness of the formation as a whole, and the underlying series of beds of sandstone and variegated shale serve to distinguish it from the upper member of the Carlile shale. The contact of the Graneros shale with the overlying Greenhorn limestone is not difficult to determine, even in places where a foot or more of transitional strata occur. The Greenhorn limestone contains no beds of argillaceous shale, and the beds of crystalline limestone at the base of the Lincoln member are sufficiently distinctive to permit ready recognition.

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[1] Identifications by J. B. Reeside, Jr.

Unsuitability for mapping. The Graneros shale is not well adapted to detailed structural mapping, for it is well exposed at but few places. The thin, hard beds in its upper part are persistent, but the more ferruginous ones in the lower part are extremely lenticular and untrustworthy. Horizontal proximity to the persistent and easily recognizable base of the Lincoln member of the Greenhorn limestone makes the use of Graneros strata unnecessary at most places. However, the Graneros shale contains the stratigraphically lowest beds that may be relied upon for tracing, and in parts of the broader, deeper valleys of Russell county it contains the only key beds available.

Name and correlation. The Graneros shale was so named by Gilbert[2] from exposures at Graneros and on Graneros creek, in Pueblo county, Colorado. Although the beds in Kansas had previously been correlated with the Graneros of Colorado by Logan,[3] Darton,[4] in 1904, was the first to apply the name Graneros to the rocks in Kansas.

The fossils found in the Graneros shale in Russell county are typical of the Graneros[5] elsewhere, but they do not indicate clearly the particular part of the much thicker Graneros of the Rocky Mountain region to which the Kansas strata are most nearly equivalent. The abundant small pelecypods are similar to forms found in western Wyoming in the lower part of the Thermopolis shale (equivalent to basal Graneros), but the cephalopod found near the top of the formation in Russell county closely resembles a form found near the top of the uppermost member of the Graneros in northeastern Wyoming.

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[2] Gilbert, G. K.; The underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 564; 1896.

[3] Logan, W. N.; The Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 232-234; 1897. Also, A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geol., vol. 7, pp. 83-91; 1899.

[4] Darton, N. H.; Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 445; 1904.

[5] J. B. Reeside, Jr.; personal communication.

DAKOTA SANDSTONE.

The thick series of beds of variegated sandy shale and lentils of sandstone that make up the bed rock in the floors and sides of the larger valleys in Russell county is the Dakota sandstone. About 160 feet of the upper part of this formation is exposed in Russell county. More than half the beds consist of shale or sandy shale, but the most prominent constituent of the formation at its outcrops is the harder sandstone. The shale is variegated and gray, sandy and argillaceous; the sand in the sandstones is well sorted. Lignite and calcareous concretions occur at some horizons. The horizontal variation in the composition of the formation is great, sandstone bodies 50 to 100 feet thick in some places giving way entirely to variegated shale within distances of less than half a mile. In general the upper 10 feet or so is regularly bedded sandstone and the lower beds are shale, but thick lenses of crossbedded sandstone occur in places throughout the formation.

The formation was named by Meek and Hayden,[6] in 1861, from exposures near the town of Dakota, in northeastern Nebraska. In Russell county, Kansas, the Rocktown channel sandstone member occurs irregularly in the upper 125 feet of the formation.

EVENLY BEDDED STRATA.

Upper sandstone unit. At most of the outcrops in Russell county a series of beds of fine- to very fine-grained, evenly bedded or massive sandstone, from 5 to 20 feet thick, lies at the top of the formation, but in places this unit is absent. Wherever found, these beds of sandstone contain more highly ferruginous layers and fairly abundant plant remains consisting of pieces of carbonized wood, or flat, vertical, grasslike marks. Despite the regularity of bedding, the individual layers are very discontinuous, the top of the formation in some places varying 10 feet in stratigraphic position within a few hundred feet along the outcrop (Fig. 6). A few miles northwest of Lucas a concretionary bed of tan sandy limestone about an inch thick occurs at or near the top of the formation.

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[6] Meek, F. B., and Hayden, F. V.; Descriptions of new lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary fossils collected in Nebraska Territory [etc.]: Phila. Acad. Nat. Sci. Proc. 1861, vol. 13, pp. 419-422; 1862.

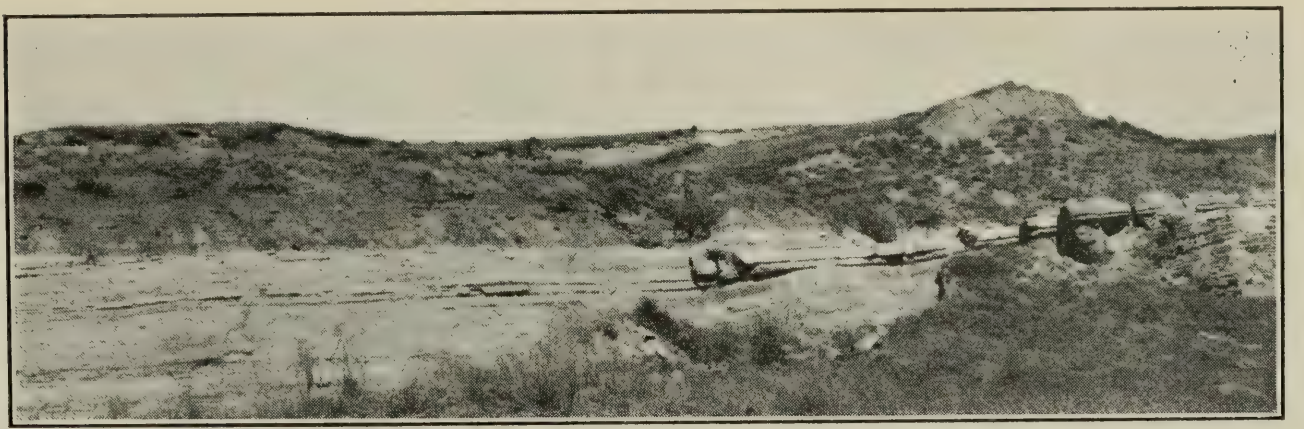

FIG. 6. Contact of the Graneros shale and Dakota sandstone. Lensing strata of evenly bedded sandstone at top of Dakota formation make contact about 8 feet lower stratigraphically in right foreground than in left. View southeastward in NE¼, sec. 33, T. 12 S., R. 14 W., Russell county.

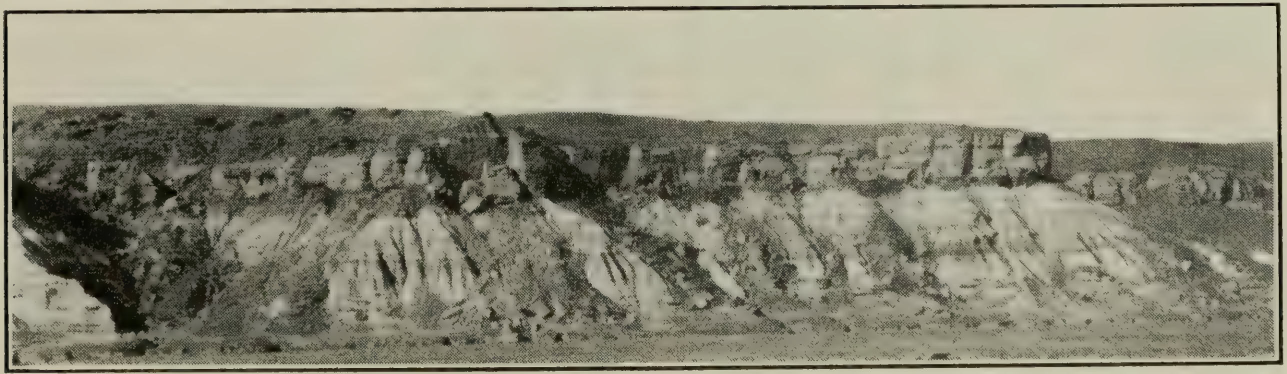

FIG. 7. Evenly bedded sandstone at the top of the Dakota formation, underlain by variegated shale that is intricately dissected into "bad-land" slopes. View northeastward, sec. 34, T. 12 S., R. 14 W Russell county

Lignitic beds. In the southeastern half of Russell county beds of lignite from 1 to 2 feet thick are found near the base of the upper sandstone unit, where it is present, or at the top of the formation where the sandy beds are absent. Although two coal beds were not seen in any one section, the different outcrops of coal probably do not lie at the same horizon, although all may fall within one general zone. The lignite in these beds is apparently composed entirely of broken fragments of carbonized wood with which some silty material is intermixed. Abandoned caved prospect tunnels and mounds of shale dumps at many places in the area show that rather extensive but futile efforts have been made to discover commercial deposits of coal. It is reported that considerable coal was actually mined many years ago on Coal creek near the southwestern corner of the county.

Clay shale beds. Under the evenly bedded sandstone and lignite beds in Russell county lies a series of light gray, fissile, gritless clay shale, containing some hard, ferruginous and sandy beds a few inches thick. This unit is generally 15 to 40 feet thick, but in many places it is absent. Some of the thin layers of sandstone contain fragments of carbonized wood. Ferrous sulphate occurs on weathered surfaces of these beds, giving them a peculiar bitter taste.

Variegated mudstone unit. The gray clay grades downward and in some places laterally into hard, massive light greenish gray shale or mudstone mottled with subordinate amounts of bright to dull cherry, maroon, lavendar, brown, and tan. The beds of variegated mudstone alternate with layers of dark gray to black carbonaceous clay. This variegated mudstone is chiefly sandy, but some layers in nearly every section examined are grit-free clay. Small, limy, nodular lenses cut more or less obliquely through the exposures, and thin discontinuous beds of white to heavily rust-stained sandstone occur throughout the unit. At one place, in sec. 4, T. 13 S., R. 11 W., Russell county, a very hard, pyritiferous, sandy, calcareous concretion about 4 feet in diameter was found about 125 feet below the top of the Dakota sandstone. The bedding of the surrounding sandstone is continuous into the concretion. Ferrous sulphate and layers of carbonized wood occur at a few horizons in this unit. The variegated shale extends at least to the lowest strata of the Dakota sandstone exposed in Russell county; that is, to a depth of 160 feet below the top of the formation.

ROCKTOWN CHANNEL SANDSTONE MEMBER.

Occurring locally at almost any horizon from the top to 125 eet below the top of the Dakota sandstone there is a series of very liscontinuous, highly cross-bedded sandstone strata that is here iamed the Rocktown channel sandstone member of the Dakota andstone.

Lithology. These beds are generally hard where exposed to veathering, but unconsolidated back an inch or so from the outrop. Although the rock is rather uniformly a light buffy gray vhere fresh, the weathered exposures of it show all shades of rown, yellow, red, and gray. A few thin lenses of fissile, bluishray shale are interbedded with the sandstone. The beds of sandtone vary greatly in thickness within short distances. In sec. 3, . 13 S., R. 14 W.; secs. 5 and 9, T. 13 S., R. 12 W., and elsewhere n Russell county, cross-bedded sandstone crops out in thicknesses f more than 25 feet on one side of a narrow valley, but only gray nd variegated shale is seen at the same stratigraphic position on he opposite side. Clean exposures show that changes of thickness o abrupt take place either by interfingering of the sandstone and hale, as in sec. 11, T. 13 S., R. 12 W., where the cross-bedded sandtone strata thicken 15 or 20 feet at their base in about 200 feet long the outcrop (Fig. 8), or by local unconformity, as in sec. 22, . 12 S., R. 13 W., where the base of the sandstone cuts more than 5 feet into the underlying shale (Fig. 9).

The sandstone is fine to coarse grained, its grains ranging from ess than 0.06 to more than 10 millimeters in diameter, but most of hem in nearly all the samples examined ranged from 0.1 to 0.5 nillimeters, with 0.25 the commonest diameter. The grains of sand re finer where the sandstone grades laterally into shale. Despite he great difference of size of grains in different pieces of the rock, ndividual samples were nearly all very well sorted, the largest rains being uniformly only twice the diameter of the smallest bundant grains. The sandstone consists mainly of grains of coloress quartz, but it includes grains of pink transparent quartz, black paque fragments, and pebbles of clay, the largest 10 millimeters n diameter. Clay pebbles are generally considered proof that the eds containing them were exposed to the air during at least part of he time of their deposition. The finer-grained samples contain lso flakes of muscovite, and a red, probably secondary powder

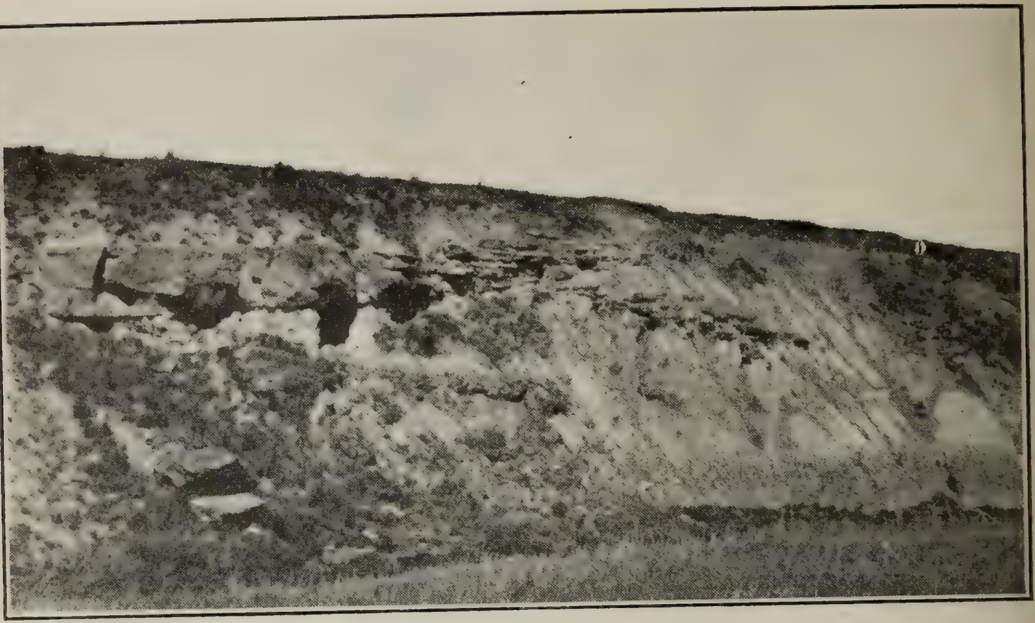

Fig. 8. Interfingering of Rocktown channel sandstone member and variegated shale in the Dakota sandstone, in sec. 11, T. 13 S., R. 12 W. View westward.

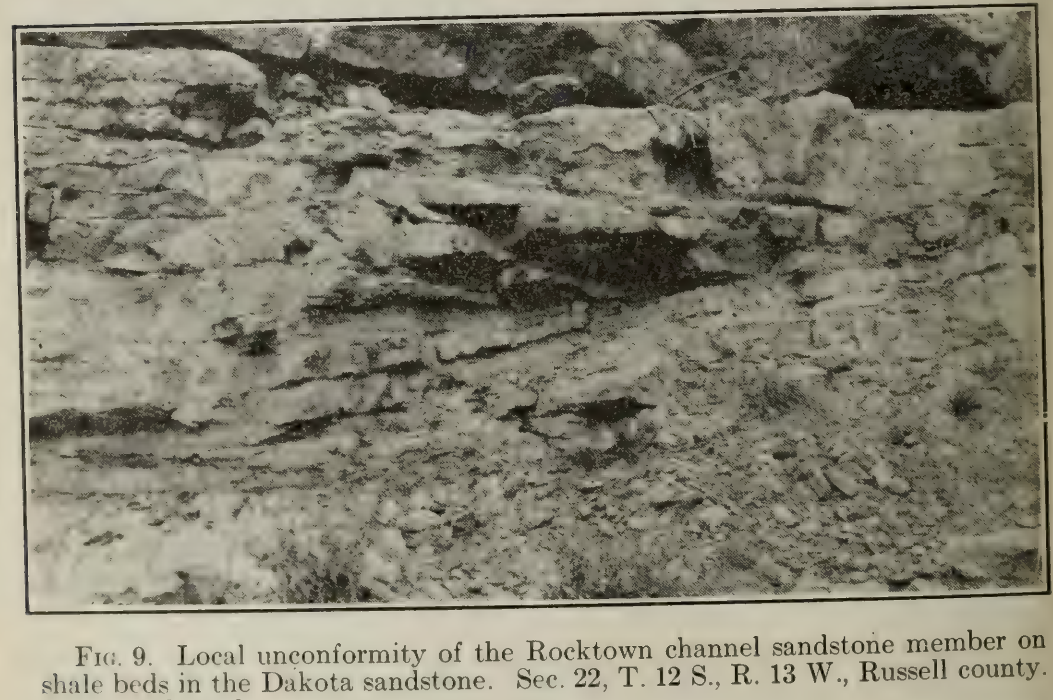

Fig. 9. Local unconformity of the Rocktown channel sandstone member on shale beds in the Dakota sandstone. Sec. 22, T. 12 S., R. 13 W., Russell county. View northward.

fills the interstices of some of the weathered samples. The grains range from highly angular to well rounded, but in almost every hand specimen collected most of them are subangular. Some at least of the extreme angularity found is due to recrystallization. The larger fragments in general are better rounded and show more or less of the "ground-glass" or "frosted" surface generally thought to be produced by wind action.

The cross-bedded laminæ in this member dip from 5° or less to nearly 30° in every direction, but dips of about 22° southwest, west or northwest are most common. Within one stratum that shows oblique bedding the dip is slightly steeper at the top and flatter at the base—that is, the lower cross-bedded laminæ become more nearly tangent to the base of the stratum—and in the thicker strata this condition is at some places very striking. The diagonal laminæ are in beds from 1 inch to 8 feet thick, though 6 inches to 3 feet is the more usual range; or, to put it in another way, the foreset beds are commonly from 1½ to 8 feet long. The beds that show oblique lamination are generally separated by evenly bedded, somewhat thinner strata, but at many places two cross-bedded layers are in immediate contact and the top of the lower layer is abruptly truncated by the upper. In general, though not in detail, the cross-bedding has the same direction throughout any particular vertical series. The bounding planes between the cross-bedded and non-cross-bedded strata are nearly but not strictly parallel; that is, each individual stratum, although of nearly uniform thickness throughout, varies somewhat. In some places these bounding planes dip a few degrees either at right angles to or nearly in the opposite direction from that of the cross-bedded laminæ. Nearly all these features (alternating and essentially parallel layers of rather thin, cross-bedded and thinner evenly bedded strata with the successive cross-bedded layers dipping in the same direction) are peculiar to the torrential type of cross-bedding[7] that is characteristic of stream-channel deposits. However, it is conceivable that this type of cross-bedding might be formed in the sediments deposited in delta distributaries and marine straits.

Distribution of the sandstone lenses. The lenticularity, composition and bedding of the member afford much evidence that it was deposited by streams, and with this interpretation in mind an attempt was made to determine the course of the possible streams

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[7] Grabau, A. W.; Principles of stratigraphy, pp. 590, 702-703, 704-706; 1913.

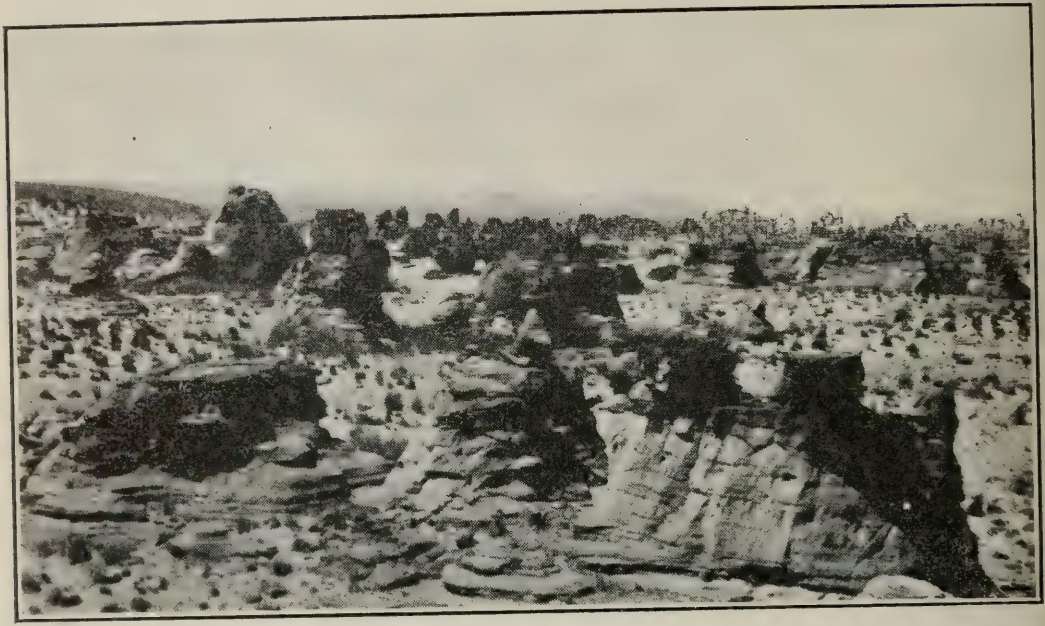

Fig. 10. Sandstone "hoodoos" in Rocktown, in sec. 4, T. 13 S., R. 11 W., Russell county. Rocktown channel sandstone member of Dakota sandstone weathered into vividly stained houselike blocks.

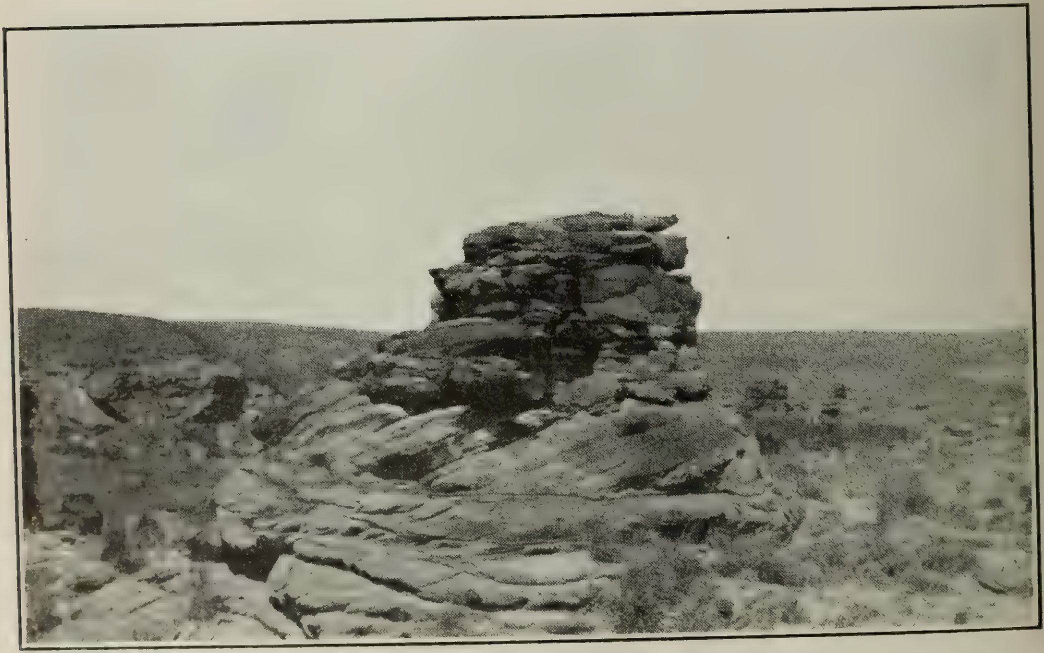

Fig. 11. A sandstone "hoodoo" in Rocktown. A weathered projecting mass of Rocktown channel sandstone, in sec. 4, T. 13 S., R. 11 W., showing oblique laminæ dipping westward.

rom the now disconnected lenses of sandstone. These sandstone entils appear to lie in long, more or less sinuous belts a few miles or less wide, the most conspicuous of which are those in the valley of Saline river, in the eastern part of Russell county. The approxinate parallelism of the direction of cross-bedding with the elongaion of these lenses observed at a number of places furnished a clue or the interpolation of the supposed channels where the sandstone enses are buried by younger rocks or removed by later erosion. By this process it was found that all but a very few of the sandtone lenses near Saline river fall into one meandering zone that ndicates a general westerly direction of flow of the depositing tream. The remaining isolated lenses suggested tributary streams, nd in some places a braided condition of the channel, and even hannels that diverged westward from the main zone. However, n determining this preliminary zone the stratigraphic position of he different sandstone lenses had not been considered. By taking nto account the relative ages of the lenses (the interval to the top of the Dakota sandstone), the direction of cross-bedding at different tratigraphic positions, and the usual changes in the course of a neandering stream, a second series of zones was drawn (Plate III). For instance, in sec. 22, T. 12 S., R. 13 W., and in sections to the orthwest, the sandstone is from 20 to 75 feet below the top of the Dakota sandstone and cross-bedded northwestward, but from sec. 31, T. 12 S., R. 13 W., to sec. 6, T. 13 S., R. 14 W., it is at or near he top of the formation and the cross-bedding dips west-southwestvard. This was taken to mean that the stream first flowed northvestward from sec. 22, T. 12 S., R. 13 W., but that after the valley ad been more nearly filled by alluviation it flowed westward in a ew channel. Also, in sec. 31, T. 12 S., R. 13 W., where the stream nay have flowed but a short time, the sandstone is only 15 feet hick, but in sec. 4, T. 13 S., R. 11 W., where the stream is supposed o have remained much longer, the sandstone accumulated to a hickness of 100 feet. This conception of various stages of meanlers seems to explain all the sandstone lenses observed in the valley of Saline river as the deposits from one continuous, meandering, hifting stream with one or two smaller tributaries.

Plate III shows the outcrops of cross-bedded sandstone and the observed directions of most prominent cross-bedding in the member. It also shows approximately the location of the more or less obscured and eroded connections between the isolated lentils of andstone.

Cross-bedded sandstone was noted in other outcrops of the Dakota sandstone in Russell county, but the lenses are thinner and the outcrops more isolated. The fortunately close coincidence in the position of the old channel with the present valley of Saline river makes possible a reconstruction of the old stream course, and whether or not there are other parallel or tributary channels is not definitely known.

Name. The Rocktown channel sandstone member is named from the excellent exposures of the member at and near the large group of "hoodoos" or houselike blocks of sandstone in the northwest quarter of sec. 4, T. 13 S., R. 11 W., locally known as Rocktown.

ORIGIN.

The Rocktown member was evidently laid down by a rather large stream, which in Cretaceous time flowed westward through Russell county. The ground-glass surface found on some of the sand grains may have been developed far to the east and the grains transported to Russell county by the stream; or wind drifting of sand on bars and shores much nearer may have caused it.

The environment assumed in explanation of the origin of this member suggests interpretations of the conditions of deposition of some of the associated units in the Dakota sandstone. The variegated and carbonaceous mudstones in which the Rocktown member is interbedded might be interpreted as silts and fine sands deposited in the back waters of wide flood plains, the various colors possibly being due to different degrees of oxidation. The gray clay shale might by the same reasoning be explained as muds deposited in deeper, more permanent bogs where they were at no time exposed to the effects of weathering. The occasional lenticular ferruginous layers might be the result of the precipitation of iron carbonate in local bogs. The evenly bedded sandstone unit at the top of the Dakota may have been deposited as beach sands, the immediately ensuing marine Graneros shale and the general aggradation of the stream valley suggesting an encroachment of the sea. The fragmental silty lignite beds may have been transported from elsewhere and formed from buried accumulations similar to log jams, but their position just below the possibly marine upper sandstone unit suggests that they may be the result of tidal marsh deposition.

FOSSILS IN THE DAKOTA SANDSTONE.

Plant remains are essentially the only fossils found in the Dakota sandstone in and near Russell county. Well-preserved leaves of

Lomatia? saportanea (Lesquereux) Lesquereux, *Sassafras mudgii* Lesquereux, *Celtis? ovata* Lesquereux and *Populus* sp.,[8] were obtained in a highly ferruginous layer at the very top of the Rocktown member (there about 20 feet below the top of the Dakota sandstone) n the southwest quarter of sec. 22, T. 12 S., R. 13 W. Fragments of eaves occur in heavily iron-stained beds in the shale and at the top of the cross-bedded sandstone at several places in and near Russell ounty, from 20 to 55 feet below the top of the formation. Indistinct lant stems and fragments of carbonized wood were noted at many laces throughout the formation. Cylindrical marks that are prob-bly worm tubes were found in the uppermost regularly bedded sand-tone of the Dakota sandstone in sec. 6, T. 15 S., R. 10 W., Ellsworth ounty. No vertebrate or invertebrate remains were noted, but ortheast of Russell county, in Lincoln and Mitchell counties, marine nvertebrates of Upper Cretaceous age [9] have been found in the beds ear the top of the formation. Southeast of Russell county, in aline, Ellsworth and McPherson counties, marine invertebrates ave been found in Comanche strata in the lower 100 feet[1] of the andstones and shales immediately below the Dakota sandstone.

VARYING PROMINENCE.

The Dakota sandstone, because of the extreme lenticularity of its arder beds and the wide range in the color of its beds of shale and andstone, is one of the most striking formations that crop out in ussell county. Except for the lentils, however, it is rather soft, nd makes broad, flat valleys. The hard variegated shale is at many laces prominently exposed in intricately dissected bluffs—a typical bad-lands" surface on a small scale (Fig. 7)—but the dark clay hale near the top of the formation is soft and is well exposed at but w places. The uppermost evenly bedded, fairly persistent sand-one makes a series of flat benches below the Graneros outcrop, the umber of scarps depending upon the number of hard ferruginous r sandstone layers in the section. The Rocktown sandstone member rms a peculiar topographic feature where slightly harder parts of s outcrops weather to groups of "hoodoos"—more or less isolated, regularly shaped cones or blocks from 5 to 15 feet high (Figs. 10

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[8] F. H. Knowlton, who identified these fossil plants, reports that all are well-known kota species.

[9] Stanton, T. W.; Some problems, connected with tht Dakota sandstone: Bull. Geol. c. America, vol. 33, pp. 259-261; 1922.

[1] Twenhofel, W. H.; The Comanchean of central Kansas: Kansas Acad. Sci. Trans., l. 28, pp. 213-223; 1917.

——— The Comanchean and Dakota strata of Kansas: Am. Jour. Sci., 4th ser. vol. , pp. 281-297; 1920.

and 11). The sandstone in these weathered blocks shows vivid colors—bright reds, yellows and rich browns alternating with buff, white and gray.

The residual soils on the outcrop of the Dakota sandstone are usually very sandy, but in most of Russell county the formation is obscured by a later covering of alluvium. In many places yucca grows rather abundantly where this formation is at the surface. Seeps of water from the base of sandstone ledges are fairly common in the deeper valleys.

SIMILARITY TO OTHER STRATA.

The Dakota sandstone is the only Cretaceous formation in Russell county that contains variegated shale and much sandstone. Cenozoic deposits are also sandy, but are almost invariably coarser and contain many fragments of feldspar and particles of rock not found in the Dakota sandstone. The soft beds of fissile clay shale generally found near the top of the Dakota resemble those of the Blue Hill member of the Carlile shale and the Graneros shale. The abundant calcareous concretions in shale beds of the Blue Hill member and the thin sandy layers common in the shale in the Dakota sandstone serve readily to distinguish the two. The Graneros shale, however, cannot be easily differentiated from the Dakota sandstone everywhere, for sandstone and clay shale beds are found in both. At most places the base of the fissile gray shale coincides with the top of a hard, regularly bedded sandstone, from 5 to 20 feet thick, which lies about 40 feet below the top of the Graneros shale, but interfingering of the layers of shale and sandstone at many localities causes this contact to range through a stratigraphic interval of about 20 feet. Logs of wells in Russell county indicate that the evenly bedded sandstone is not present in some places at the top of the Dakota formation, and the underlying clay shale is quite indistinguishable from the Graneros shale. In these wells the top of the variegated shale or sandy shale, which is recorded in the logs as red shale or red rock, is doubtless at a variable distance below the top of the Dakota sandstone.

USELESSNESS OF THE DAKOTA SANDSTONE FOR MAPPING OF STRUCTURE.

The Dakota sandstone is practically useless for detailed mapping. No bed within the formation is persistent throughout the county, and possibly no one layer can be traced more than a few thousand feet horizontally, and many lenses extend much less than a thousand feet. Discontinuity alone is not the only characteristic that renders most of the beds unsuitable for use in detailed mapping of structure, for many strata cut obliquely through the adjacent beds of shale, and some of the intervals between different hard layers vary greatly within short distances. No beds in the Rocktown member are suitable for structural mapping, the lenticularity and (where the sand was deposited on a sloping surface) the primary dips of the strata and the continuous shifting of the course of the stream leaving no ayers that can be depended on. The carbonaceous and lignitic beds are discontinuous, and the fragmental nature of the constituent woody material suggests that they were not deposited in a widespread swamp of growing vegetation, as most coal beds are supposed to have been formed elsewhere, but may have been formed rom flood-carried debris deposited in local backwaters. The flatness of the flood plain suggested by the aggradation that evidently occurred and by the meandering of the channel would seem to make ome of the layers of silt or mud deposited on the flood plain fairly eliable key beds, but these silty strata are soft and sufficiently well xposed for recognition and tracing in but a few places in Russell ounty. The evenly bedded sandstone strata at the top of the formation most nearly fill the requirements for this type of mapping, but the individual layers of even this unit are highly lenticular Fig. 7). It seems that detailed structural mapping is impossible in he area of the Dakota outcrop in Russell county. It is also impracticable to drill shallow holes to some easily recognizable horion, for the well logs show that the series of beds of shale and sandtone that form the Dakota (and possibly the Comanche) is from 300 to 400 feet thick in Russell county and is underlain unconformably by a thick series of equally variable beds of red shale and sandtone.

Rocks Concealed.

Beneath the Cretaceous rocks in Russell county lie strata that belong to older geological divisions, which are more or less closely quivalent to those that appear at the surface farther east and south. The only direct information concerning these concealed rocks is that given by records of deep borings. The field work in Russell county ncluded the collection of records of drilled wells and numerous amples of drill cuttings from operators and drillers, who generously coöperated in this work. A detailed study of these data and a tentaive correlation (Plate VI) of the rock formations with those in the oil fields of central and eastern Kansas has been made by Mr. Bramette, whose report forms a part of this bulletin.

STRUCTURE.

The beds in and near Russell county lie essentially flat and undisturbed, showing only a slight regional inclination, which differs in amount and direction in different beds and is interrupted by gentle folds and small faults.

Surface Rocks.

Throughout western Kansas[2] the dip of the surface rocks is in general northward, and in Russell county, where it is north-northeastward, it averages about 7 feet to the mile. In the northern part of the county the regional dip per mile is about 12 feet, but in the southern part it is only 5 feet.

The northward dip is not perfectly smooth, for it is modified by numerous local variations. Throughout Russell county there are low domes, anticlines, terraces, structural noses, synclines and basins, so that the facetious remark that is occasionally made by geologists who have worked in the region, that a "ten-foot closure can be found in every section," is not so gross an exaggeration as it might seem. (As is discussed under the heading, "Economic significance of method of origin," very few of these small folds are thought to be favorable for the accumulation of oil.) Faults, however, are remarkably uncommon in Russell county.

Structural contour map of the top of the Greenhorn limestone. The accompanying structure contour map of Russell county (Plate IV) has been constructed almost entirely by combining the horizontal locations of the different beds sketched with the elevations shown on the topographic maps of the Russell, Osborne, Plainville, Ellsworth, Beloit and Hays quadrangles. The structure contour lines thus derived obviously cannot be correctly placed in detail. Where the regional dip is less than 10 feet to the mile, an error of 25 feet in the elevation of a key bed might cause a horizontal misplacement of a contour line of nearly 3 miles, and such an error could result (1) from uncertainty as to the surface elevation of a point between contour lines on a topographic map having a 20-foot contour interval, (2) from an inaccurate location of the outcropping strata in hasty reconnaissance mapping, and (3) from slight errors in the topographic maps. However, an attempt was made to smooth out the contour lines by using average key-bed elevations for each square mile, and rejecting even these averages if they stood above or below the surrounding area and were not verified by additional information. This smoothing and the interval chosen for the contours—50 feet—make the structure map a fairly reliable representation of the broader structure of the county. Comparisons with detailed maps prepared by company and independent geologists indicate that the map is essentially correct in its major features, but that many irregularities of small horizontal extent are omitted.

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[2] Darton, N. H.; The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, Pl. I; 1918.

Prominent northward-trending anticlines. The folds in Russell county and its vicinity appear to be divisible into two more or less distinct types—the prominent, northward-trending anticlines near the east and the west border of the county, and the smaller, less systematic folds in the remainder of the area. The persistent northward trend of some of the larger folds in Russell and adjoining counties is striking. These larger anticlines, such as the Fairport-Natoma fold and the more or less connected structurally high area in Lincoln county, near the Russell county line, are topographically rather prominent, due to the fact that they stand somewhat above the general structural level. The eastern one is not a long, simple anticline, however, for it consists of a series of elongate domes separated by structural saddles. At some places, as in an area extending northward from a point near Gorham to the northwest corner of the county, and in an area that extends northward from Wilson through the western part of Lincoln county, these anticlines are bounded on the west by a parallel but rather discontinuous syncline. An additional peculiarity of these anticlines is their parallelism to a very irregular, structurally high area west of the bounding syncline, as in the northeast corner of Ellis county and in the area extending from Dorrance through Lucas, in eastern Russell county.

The Fairport-Natoma anticline. The best developed example of the larger folds in the vicinity of Russell county is the Fairport-Natoma anticline, which is traceable in a line that runs uniformly 8° or 10° east of north for at least 20 miles along the northern half of the western border of Russell county. The dips on the west side are steeper, the rocks commonly descending at rates of 50 to 200 feet to the mile into a parallel syncline in which the beds are 100 feet or more below their elevation on the axis of the anticline. East of the axis the beds dip 15 to 40 feet to the mile. Minor domes and depressions occur on top of the anticlinal axis and in the syncline. It is in a dome on this anticline that oil and gas have been found in Russell county.

Lesser folds. The characteristics of the prominent anticlines are in contrast to the structural habit of the remainder of Russell county. The regional north-northeast dip in the wide area between the prominent anticlines is interrupted very irregularly by numerous domes, terraces and basins that are in general of small horizontal extent and that have slight structural relief or closure and no definite trends or approach to systematic arrangement. The crests of these lesser folds appear to fall into a general structural level in a way that is comparable with the accordance of summit levels in a maturely dissected peneplain topography. The synclinal and anticlinal axes are somewhat continuous over the county, but in general they are very sinuous. However, a few of these lesser structural features show alignments, though no constant structural trend is recognizable. A persistent, even if discontinuous, anticlinal axis extends northeastward from a region near Gorham to one north of Russell, and possibly to the vicinity of Lucas. A syncline trends westward from an area near the northeast corner of the county to one north of Luray. A low anticline that trends slightly east of north extends from Milberger, in T. 15 S., R. 14 W., to an area a few miles southeast of Russell. An elongation of both anticlines and synclines west-northwestward is recognizable throughout much of the northwestern quarter of Russell county. A fairly sharp anticlinal nose extends northeastward from near the southwest corner of the county for about 10 miles. (See Plate IV.)

Although the structural features in the county are divisible into the two types described, an almost perfect gradation between them may be found. In places the northward-trending axes appear to merge for miles into the homoclinal slope, as one of them seems to do south of Gorham, and the trend of one of the most persistent of the lesser folds, the one extending northward through townships 15 and 14 S., R. 14 W., is almost identical with that of the Fairport-Natoma anticline. The differences in the characteristics and the areal distribution of the two types, however, are so striking as to justify the division made, especially as these differences seem to indicate different conditions of origin. Furthermore, oil and gas have been found in paying quantities on one of the northward-trending anticlines, but neither has been found (June, 1924) on the less prominent, unsystematically arranged folds.

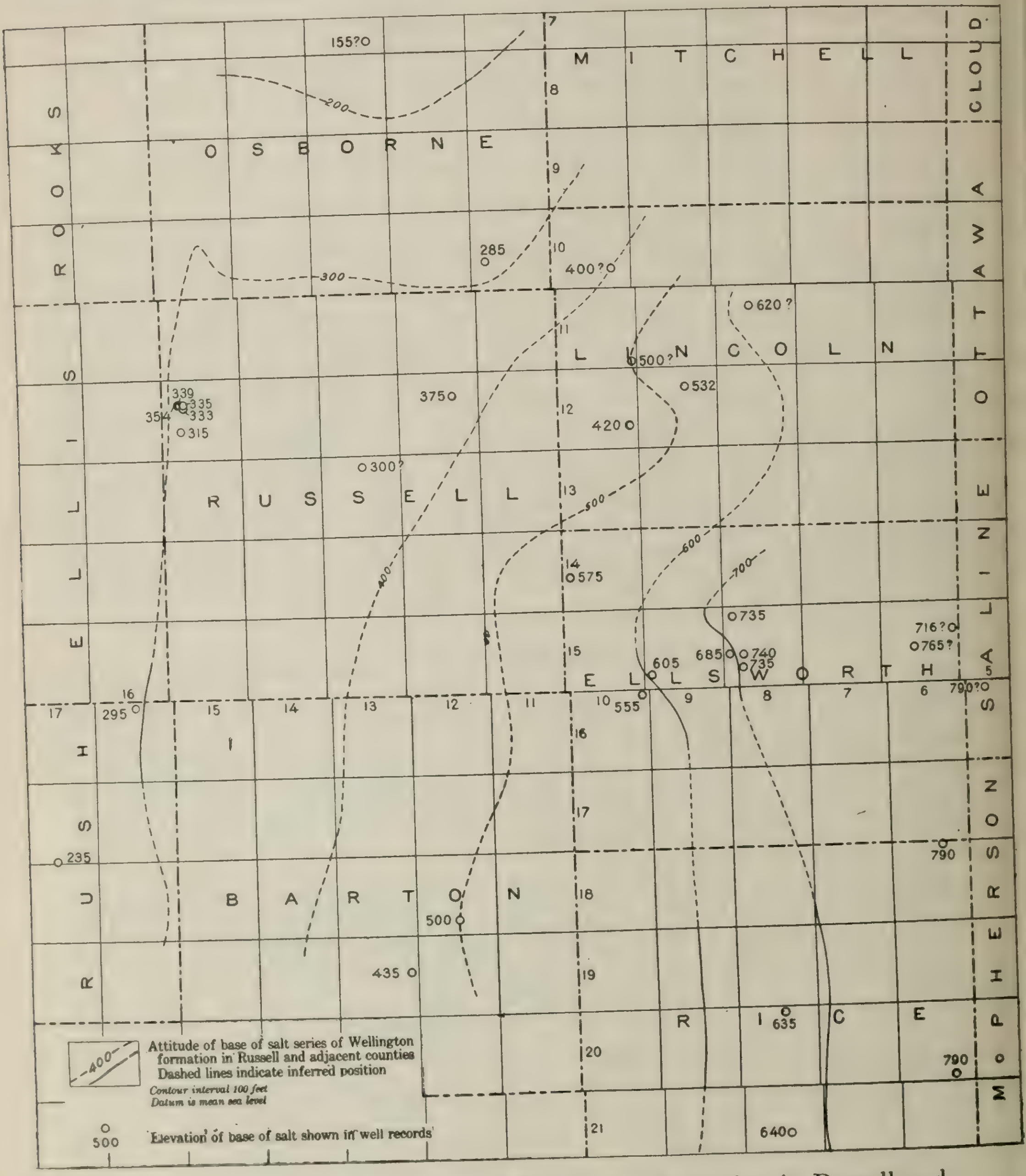
Faults. Almost all of the faults that have been found in the vicinity of Russell county are in the Niobrara formation. Three parallel faults found in the Fairport member of the Carlile shale in the NW¼, sec. 29, T. 11 S., R. 16 W., in Ellis county, 5 miles west of Russell county, strike S. 10° W., and are each downthrown a few feet on the western side. The fissures along these fault planes, which dip westward at an angle of less than 45°, are filled with veins of crystalline slickensided calcite several inches thick. The strata between these faults dip rather steeply. Farther west, in the area of outcrop of the Smoky Hill member of the Niobrara formation, faults that are similarly marked by veins of calcite are locally common and the associated beds show dips that are unusual in their direction and steepness. The faults trend in many directions. Sufficient observations were not made to justify any generalization regarding their alignment or their most persistent course. The clean exposures of brittle rock beds in the Carlile and Greenhorn formations indicate strongly that faults are not equally common east of the Niobrara outcrops. Possibly the boundary of the Niobrara outcrop chances to coincide closely with the margin of a separate structural province, but it seems much more likely that the faults are restricted essentially to the Niobrara rocks and that the lower formations have yielded to the fault-forming stresses by folding, not by breaking.

Attitude of Rocks Not Exposed.

Logs of wells drilled in and near Russell county show that the deeper beds lie nearly flat, although these deeper beds, like those at the surface, show gentle regional inclinations, which differ in amount and direction because of progressive changes in the thickness of some of the beds.

Thinning of shallower rock units northeastward. The units of rock below the top of the Dakota sandstone, recorded in well logs chiefly as sand, red rock and shale, representing the Dakota and possibly some rocks of Lower Cretaceous age, decrease in thickness eastward across Russell county from more than 400 feet near the western border of the county to 300 feet or less near its eastern boundary. The "Red Beds," which underlie the Cretaceous strata unconformably, are cut into more deeply to the east and northeast, so that over 300 feet more of this series remains uneroded near the southwest corner of the county than in its northeastern part. These two units together decrease 600 to 700 feet in thickness from east-central Rush county northeastward to northwestern Lincoln county, a distance of 60 miles. The combined effect of this thinning of Mesozoic and greater erosion of Paleozoic strata eastward is to

STATE GEOLOGICAL SURVEY OF KANSAS. PLATE V.



Attitude of base of salt series of Wellington formation in Russell and adjacent counties.

shift the regional dip in Russell county from north-northeastward in the Cretaceous rocks to westward or northwestward in the strata below the top of the Permian "Red Beds."

Map of the elevations of the base of the salt series. The accompanying map (Plate V) shows the elevation above sea level of the horizon usually recorded in logs as the base of the salt in those wells near Russell county that have been drilled to this depth. The elevations given for the mouths of wells are taken chiefly from topographic maps and are therefore only approximately correct. The logs of a number of wells in and near Russell county show a thin bed of salt from 25 to 50 feet below the thick, more or less unbroken salt unit, and in the logs of a few wells this lower bed or series of beds has apparently been included in a thick series recorded as entirely salt. For example, this appears to have been done in the M. M. Valerius Oil and Gas Company's Phillips No. 1 well, in sec. 3, T. 13 S., R. 13 W., and the base of the salt as recorded for this well is therefore probably too low. The wide, almost perfectly flat structural terrace or nose indicated in Russell county and in areas farther west presents a notable contrast to the relatively steeply inclined, westward dipping series of beds in western Lincoln and Ellsworth counties.[3]

The regional inclination of the strata below the top of the "Red Beds" is essentially parallel to that of the base of the salt series, though a gradual westward thinning of 150 to 200 feet in a 1,500-foot section of the beds below the base of the salt makes the westward dip somewhat gentler in the lower beds.[4] The records of wells that are near together, however, show significant differences in the thickness and structure of the buried rocks.

Increasing steepness of dip with depth below surface. The logs of the first four wells drilled in secs. 8 and 17, T. 12 S., R. 15 W., on the Fairport-Natoma anticline, show a progressive divergence of the buried strata that results in steeper dips on the successively lower beds. The westernmost of these four wells, the Stearns and Streeter Company's Ed Oswald No. 1, in the SW¼ SW¼ of sec. 8, starts at a point that is about 15 feet higher structurally than the

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[3] Wells drilled since this report was written indicate some errors in the location of the contour lines in Lincoln and Rice counties. The necessary changes are so small and the information is still so very incomplete that a revision of Plate V at this time seems unnecessary.

[4] Wells in and near Russell county that have been drilled recently indicate the presence of an unconformity 100 to 400 feet below the oil-bearing horizon. These wells indicate that from the producing field the early Paleozoic rocks slope gradually eastward about 10 or 15 feet to the mile to the eastern part of the county, and that they fall on an average of about 30 feet to the mile northward along the axis of the Fairport-Natoma anticline to the north line of the county, about 15 feet to the mile southward to the southwest corner of Russell county, and perhaps more than 100 feet to the mile westward for three miles.

Valerius Oil and Gas Company's Jesse Muncell No. 1 well, in the NW¼ NE¼ of sec. 17, less than half a mile to the east. The top of the 40- to 50-foot bed of anhydrite encountered at a depth of about 900 feet, however, is about 32 feet lower structurally in the southeast than in the west well. The top of a 20- to 30-foot series of red rock or red shale that was found at depths ranging from 1,624 to 1,659 feet in these four wells shows an eastward dip that makes the bed about 49 feet lower in the Valerius company's well than in the Stearns and Streeter well. The top of a series of beds recorded as red rock or red shale at depths of 2,057 to 2,116 feet is about 73 feet lower structurally in the southeastern than in the western well. The bed of rock 4 to 10 feet thick, recorded as sand, lime or sandy shale, and as yielding water or showings of oil, occurring from 2,590 to 2,658 feet in these wells, is about 82 feet lower in the Valerius than in the Stearns-Streeter well. That is to say, a divergence of about 65 feet occurs rather uniformly through a stratigraphic interval of 2,600 feet in a horizontal distance of less than half a mile. The resulting increase in the steepness of dip with increase of depth is a feature that is common in the oil fields of the Midcontinent region.

Origin.

By W. W. Rubey.

The origin of the structure of an isolated oil field cannot be determined, nor even satisfactorily discussed, until a great deal of drilling has been done in the region; that is, no final statements can be made about the origin of its structure until a field has passed its period of maximum productivity. However, many facts bearing on the manner in which the deformation occurred are known early in the history of a region, and additional inferences may be made by comparison of the region with near-by, similar and better-known fields. Since a knowledge of the origin of the structure of a field is an extremely valuable guide to the prospecting of it for oil, it is desirable to bring together these scattered bits of evidence and to formulate whatever theories seem justified before complete information is available. Theories so formulated, even if erroneous, are valuable in that they point out critical observations that can be made later.

The origin of the structural features in Russell county is probably closely related to the origin of similar features elsewhere in the

Midcontinent oil field, for both geographically and in the structure of its surface rocks, Russell county seems to be a part of that field. As sufficient drilling has not been done to determine the structure of the buried rocks in Russell county, it is helpful in discussing the method of formation of the folds there to make use of the more complete data that have been gathered and partially analyzed in other parts of the Midcontinent field.

The widespread presence in the Midcontinent oil field of minor folds at great distances from areas of orogenic disturbance has given rise to much speculation regarding the origin of these folds. Simple horizontal compression has been generally considered inadequate to form them, because of the incompetency of the soft shale beds, in which the folds are usually developed, to transmit thrusts for these great distances. The explanations of Midcontinent structure that seem most plausible may be mentioned briefly, and their possible application to the structure of Russell county considered.

CONFORMITY OF STRATA TO THE SHAPE OF BURIED LAND FORMS.

Blackwelder,[5] Mehl,[6] and more recently, Powers,[7] have developed a theory that surface folds may originate by the deposition and consolidation of sediments over an old, eroded, irregular surface. The idea common to the three authors cited is that some deposits, notably those of mud, are much more compactible than others. Thus, according to the theory proposed, beds of mud deposited around a hill of hard rock—granite, limestone or sandstone—would be more greatly reduced in volume by the pressure of beds subsequently deposited upon them than would the harder rocks, and the beds above the hill, therefore, would form an anticline or dome that would conform in shape with the buried mass of hard rock. Satisfactory data on the amount of cubic compressibility of mudstones are apparently lacking, and quantitative tests of the adequacy of the process outlined, though highly desirable, cannot readily be made. However, the theory merits consideration, for it accounts for features that are not readily explainable otherwise, and as deeper wells are being sunk in many oil fields from Texas to Kansas, evidence is accumulating to strengthen it.

If this process produced anticlines over large buried hills of hard rock, it should likewise produce, although less conspicuously, a reflection of the entire buried topography, for few hills are truly isolated, and in some land surfaces, valleys that lie below the general level cause greater local relief than do hills and ridges. It would therefore appear that structural features caused by the unequal settling of sediments over an irregular surface should show in a broad way, though of course with gentler slopes, the configuration of the old surface. If the old surface had been more or less reduced to slopes, broadly sinuous anticlinal axes—the old divides—from which more or less elongated structural noses extend, should be definitely recognizable if sufficiently large areas are studied. Stream valleys should appear as intricately curving and repeatedly branching but gentle synclinal axes. Domes, generally more or less elongate, would commonly be found on the anticlinal folds over the junctions of the primary, secondary and tertiary stream divides, but, if no other factor had been operative in the formation of the structure, basins or "closed" synclines should be very rare. Wells drilled in areas where the structure was so formed would find the deeper beds dipping more and more steeply and more nearly in conformity with the buried land surface, but the form or structure of the beds beneath the unconformity would have little relation to that above.

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[5] Blackwelder, Eliot; The origin of the central Kansas oil domes: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 89-94; 1920.

[6] Mehl, M. G.; The influence of the differential compression of sediments on the attitude of bedded rocks: Science, new ser., vol. 51, p. 520; 1920 (abstract).

[7] Powers, Sidney; Reflected buried hills and their importance in petroleum geology: Econ. Geology, vol. 17, pp. 233-259; 1922.

Effect of Buried Lenses of Sandstone.

A modification of the theory of settling, held by Gardescu and Johnson,[8] and others,[9] is that lenses of some less compactible rock, such as sandstone, would, by the greater consolidation of the surrounding shale, be reflected as anticlinal ridges in the structure of the overlying beds. Interfingering of sandstone and shale is commonly observed in the younger Paleozoic sediments of the Midcontinent oil field at their outcrops, and well logs show that similar lensing occurs in beds not exposed.

The shape and arrangement of folds formed by the compacting of sediments over lenses of sandstone should be governed by that of the lenses: (1) Lenses made by stream deposition would be elongate, generally curving, occasionally branched or braided, and would vary in thickness because of changes in the course or rapidity of flow of the stream. The structure developed over such a body of sand, according to this theory, should be a sinuous, elongate, but more or less discontinuous anticline from which but few subsidiary axes (the tributaries) extend. Because of variations in thickness, small, elongate domes and basins should be superimposed upon the anticlinal axis. If no other factors were at work, the area on both sides of the anticlinal axis should be structurally flat. (2) Sandstone lenses formed in the sea by offshore bars would be extremely elongate, very straight (except for occasional sharp offsets and terminal curves), and, if restricted to one horizon, relatively narrow. Anticlines formed over such beds of sandstone should be nearly unbroken for miles and should have few irregularities along the crest line. (3) A lens of sandstone deposited at a shore line would be elongate in a more or less irregular line, and whether derived from streams or caused by local weathering, would become gradually and unequally thinner seaward and along the shore from its source. Structure resulting from the consolidation of beds over such a body of sand should show a gentle terrace, merging into a flat area on one side—the seaward—and possibly to structure characteristic of that formed over a buried land surface on the other. Few irregularities should occur on the very gentle, broad fold formed on the lens of sandstone of this origin. (4) The relatively extensive deposits of sand formed by tidal or current sweeps would not be likely to result in folds sufficiently acute to be discernible in surface structure. (5) Wind-blown sandstones accumulated on land would be so rarely preserved as thick detached masses that lenses thus formed may be disregarded in the present discussion.

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[8] Gardescu, I. I.; and Johnson, R. H.; The effect of stratigraphic variation on folding: Am. Assoc. Petroleum Geologists Bull., vol. 5, pp. 481-483; 1921.

[9] Monnett, V. E.; Possible origin of some of the structures of the Midcontinent oil field: Econ. Geol., vol. 17, pp. 194-200, 1922.

An important characteristic of any folds that might be formed over lenses is that the structure below the horizon of the lenses would be relatively flat; no corresponding anticline would be found deeper.

STRUCTURE IN SURFACE ROCKS FORMED BY MOVEMENT ALONG DEEP-SEATED FAULTS.

Fath[10] has called attention to the regional alignment of *en échelon* faults, of folds, and of the buried "granite ridge" of eastern Kansas, and has pointed out that recurrent horizontal and vertical movements along buried fault planes or shear zones in more competent rocks would account for these features. Fath's explanation of the *en échelon* faults, which is the key to his interpretation of the other features, follows R. T. Chamberlin's[1] conception of the origin of a similar series of oblique faults in south-central Montana. Briefly, it is that horizontal differential movement will produce cracks at angles of about 45° to the direction of the movement. Fath's major contribution to the idea was his recognition that the deeply buried, more competent rocks would transmit a horizontal thrust for great distances and that planes or zones of weakness in these rocks would serve to localize the effect of the differential movement and form a series of parallel faults. The folds he interpreted as the effect of slumping of higher soft beds over minor fault planes, that, starting just above the more competent rocks, did not reach the surface. Subsequent investigations[2] in Osage county, Oklahoma, and elsewhere have further verified the facts demonstrated by him and strengthened the validity of his major premises.

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[10] Fath, A. E.; The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey Prof. Paper 128; 1921.

[1] Chamberlain, R. T.; A peculiar belt of oblique faulting: Jour. Geology, vol. 27, pp. 602-613; 1919.

Fath also carried his conception of zones of weakness in deeper rocks to the parallel "granite ridge" of Kansas, pointing out that the great length of this ridge—more than 170 miles—and its straightness could more plausibly be explained as a result of faulting or slipping along zones of weakness in pre-Pennsylvanian rocks than of folding or of purely erosional development of the mountains before younger deposits buried them. Moore,[3] in a summary of the known facts regarding the "granite ridge" of central Kansas, which he calls the Nemaha mountains, concludes that the igneous rocks could not be intrusive, but that the younger beds must overlie the crystalline rocks unconformably. The evidence indicates that this unconformity is probably post-Mississippian and pre-Pennsylvanian. According to these interpretations, the ridge was formed by the faulting of early Paleozoic beds of limestone, which were deeply eroded before the Pennsylvanian sediments were laid down upon them. The major lines of weakness postulated by Fath might possibly have been formed at the time of this faulting, but the great extent of the ridge and its great distance from areas of pronounced orogenic activity in Mississippian time make it appear more probable that such lines were first blocked out during a time of great widespread disturbance—perhaps pre-Cambrian—and that regional stresses at the close of the Mississippian caused the early Paleozoic rocks to break along these old lines.

The series of faults in northern Oklahoma, along which slight movements have obviously occurred since the Pennsylvanian strata were deposited, led Fath to suppose that the folds at the surface over the "granite ridge" were formed by repeated movements along the major zones of weakness. By postulating these recurrent later movements and local unconformities, he seeks also to explain the progressively greater steepness of the beds of rock on the anticlines with increase of depth.

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[2] By members of the U. S. Geological Survey, the writer among others.

[3] Moore, R. C.; Geologic history of the crystalline rocks of Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 2, pp. 98-113; 1918.

More recent drilling in Kansas, Oklahoma and Missouri indicates that other "granite ridges" lie parallel to the Nemaha mountains and the oblique fault belts in northeastern Oklahoma. Wells drilled near the Missouri-Kansas line have found igneous rocks above their expected depth from Miami, Okla., north-northeastward to a point less than 75 miles south of Kansas City, Mo., and scattered wells drilled farther east in Missouri have also reported granite at unexpectedly high elevations. In northeastern Oklahoma granite has been reported in a number of wells that are so located as to suggest several roughly parallel ridges extending (1) from Muskogee to Vinita, (2) through Rogers and Nowata counties, (3) from a point south of Tulsa past Bartlesville to a well near Iola, Kan., and (4) from the Cushing oil field to Hominy. Other wells drilled into granite east and west of the Nemaha mountains in Kansas suggest the existence of other parallel ridges.

R. C. Moore, in a forthcoming paper, considers the relation of the "granite ridge" to the structure of the overlying rocks and calls attention to certain structural features of the outcropping beds that seem to mark the position of the buried ridge. He points out that the parallel line of similar structural features in the outcropping beds from a point southwest of Eureka, Kan., nearly to Frankfort, Okla., may also overlie a buried ridge.

The scattered granite wells, combined with the evidence of the line of steeply dipping surface rocks and the belts of *en échelon* faults, indicate more than a half-dozen long parallel ridges or deep-seated faults in eastern Kansas, northeastern Oklahoma and western Missouri.

Several bits of evidence indicate that long and straight northward-trending lines of deformation exist west of eastern Kansas in many parts of the Great Plains area. Rich,[4] calling attention to the narrow northward-trending area of pre-Cambrian outcrops south of Pedernal mountain and east of the southern prolongation of the Front Range in central New Mexico, to a few wells in northeastern New Mexico that were reported to have struck granite, and to small outcrops of gneissoid granite in southeastern Colorado, suggests that the large northeast-trending anticline in northeast New Mexico and southeast Colorado[5] may overlie the northward buried continuation of the mountain range exposed in the vicinity of Pedernal mountain.

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[4] Rich, John L.; A probable buried mountain range of early Permian age east of the present Rocky Mountains in New Mexico and Colorado: Bull. Am. Assoc. Petroleum Geologists, vol. 5, pp. 605-608; 1921.

In a discussion of a paper by W. J. Miller, entitled, "Pre-Cambrian Folding in North America,"[6] Miss Margaret Fuller states that a recent detailed field study of the pre-Cambrian geology of the Front Range in Colorado discloses the presence of numerous batholiths, which have arched and metamorphosed the sediments in a long northward-trending belt, and suggests that the recent arching took place along the old pre-Cambrian line of diastrophism. In eastern Wyoming, north of the Laramie mountains, the eastern margin of the Hartville uplift, the Old Woman anticline, and a steep monocline on the west side of the Black Hills, are prominent structural features trending slightly east of north that are apparently aligned.[7] The pre-Cambrian rocks exposed in the Black Hills in South Dakota are reported to have a cleavage that trends northward except where it has been destroyed by later intrusions.[8]

It is noteworthy in this connection that the broad northward-trending anticline mapped by Darton[9] in western Kansas may extend northward instead of turning northwestward as shown, for Darton admits there is little evidence for connecting the fold on the Republican river near the southern border of Nebraska with the Chadron anticline in the northwestern part of the state.[1]

Folds formed largely by readjustments along buried tectonic lines would probably possess some distinctive characteristics. Simple vertical movements would produce faults in the strata immediately above the buried lines, but soft shale beds would cause small faults of this type to be dissipated upward and expressed only as steep dips. Simply vertical movements would produce no anticlines at the surface; it would form only a monocline—a narrow line along which the beds dip steeply in one direction—with flat-lying beds on both sides. If a narrow block between two fracture lines were uplifted, the surface result would probably be a broad, flat anticline with abrupt and steeply dipping limbs. Vertical movement, accompanied by a tilting of the blocks between the major fault zones, however, might produce anticlines and synclines with dips much steeper on one limb than on the other. Horizontal movement along the tectonic lines would produce minor faults, many of which would not reach the surface, and above them folds might be formed in the manner that Fath suggests. These folds, like others formed along buried lines, would have one limb steeper than the other; they would be elongated at angles of about 45° to the buried line of weakness, and should occur *en échelon.* Pressure folds, likewise running at angles of 45° to the buried line, but lying at right angles to the commoner faults and folds produced by tension and slumping, might also be produced, but they would probably be smaller and more inconspicuous in the higher beds. Finally, none of the structural features thus produced would necessarily be long and continuous, for the amount and direction of movement along the buried tectonic lines, as Fath points out, might vary greatly within rather short distances.

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[5] Darton, N. H.; Geologic structure of parts of New Mexico: U. S. Geol. Surv. Bull. 726, fig. 16; 1922.
——— The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, pl. 1; 1918.

[6] Bull. Geol. Soc. America, vol. 34, No. 4, pp. 700-701; 1923.

[7] Darton, N. H.; The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, pl. I; 1918.
——— U. S. Geol. Survey Geologic Atlas, Newcastle Folio (No. 107), fig. 3; 1904.

[8] Van Hise, C. R.; The pre-Cambrian rocks of the Black Hills: Geol. Soc. America Bull., vol. 1, pp. 209, 231-233, 241; 1890.

[9] Darton, N. H.; The structure of parts of the central Great Plains; U. S. Geol. Survey Bull. 691, pl. I; 1918.

[1] Idem, p. 12.

FOLDS FORMED BY LEACHING OF SALT BEDS.

Leaching of easily soluble beds might cause slumping of the overlying beds on a scale sufficiently large to form folds. This mode of origin cannot be ascribed to the folds in most of the Midcontinent oil fields, for no easily soluble beds are found there in sufficient thickness to make the effects of this leaching significant. In western Kansas, however, a persistent series of beds of salt, from 200 to 400 feet thick, underlies the surface rocks. The high solubility of salt and the saltiness of most of the ground waters in that region suggest that the thinning of this series of beds by partial solution might there produce features of the structure. Basins that have sunk several feet within historic time, in Meade county, Kansas, have been thus accounted for by some writers.[2] Unsaturated water capable of dissolving the salt out of these beds would presumably come from near-lying aquifers or would seep down from the surface. It would probably find access to the salt beds only in faulted zones and at places where porous beds lay in contact with them.

Logs of wells in central Kansas show only slight variations in the thickness of the salt beds, whether the wells are or are not on anticlines—a fact that tends to weaken the theory. This process is not regarded as impossible, but it is probably not of great importance nor of wide applicability in western Kansas. The structural features developed by this means should be wide flats, interrupted locally—or possibly in zones along faults—by basins or closed synclines.

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[2] Coffey, G. N., Rice, T. D., and others; Reconnaissance soil survey of western Kansas: U. S. Dept. Agric., Bur. Soils, p. 10; 1912.

APPLICATION OF PRINCIPLES TO STRUCTURE OF RUSSELL COUNTY.

The regional dip of the rocks in Russell county may be the result of broad deformation or tilting, but it is believed that the folds superimposed upon the regional homocline must have been caused by processes other than horizontal compression.

Gentle, unsystematic folds. The irregularity of trend of the axes of the folds throughout the greater part of Russell county suggests a mode of origin other than by horizontal compression, localization along buried tectonic lines, or consolidation over long lenses of sandstone formed as offshore bars, all of which methods of origin would probably form long, straight folds. It does not seem that the larger, at least, of these unsystematic folds can be explained as due to the compacting of sediments over local lenses of sandstone or the leaching out of salt beds. Rather, the sinuous and branching character of the gentle anticlines and synclines suggests that they may be largely due to unequal consolidation of the beds laid down on an old land surface.

According to this explanation, the structurally flat areas in the southern part of the county would be the surface reflection of a fairly smooth buried surface, on which the valleys and ridges ran in general northeastward or northward. The more steeply dipping beds in the northern part of the county would have derived their inclination from a more intricately dissected surface, on which most of the stream valleys and interstream divides extended eastward. The direction or directions of slope of these two hypothetical surfaces is unknown. Similar studies of adjacent counties may show whether the valleys enlarge to the northeast or southwest, or in both directions.

Basins or closed synclines, such as those in the northeastern part of Russell county and many smaller irregularities of structure not shown by the generalized contour lines of Plate V, seem to demand another explanation, however. Sandstone lenses that lie above and are elongated across buried valleys might produce in the overlying rocks anticlinal folds that cross the "valley" synclines and thus give rise to closed basins on their "upstream" sides. The thicker parts of the Rocktown channel sandstone member of the Dakota sandstone, though perhaps never deeply buried, coincides in position with structurally high areas in central and east-central Russell county in such a way as to suggest that they may have modified somewhat the structure that was produced chiefly by other agencies. Sandstone lenses in the more deeply buried Pennsylvanian sediments would produce similar and perhaps more acute effects. Slumping over dissolved salt beds might also form some basins.

Prominent, northward-trending anticlines. The foregoing theory of origin may apply to the unsystematic gentle folds that are widely scattered over most of Russell county, but the prominent northward-trending structural features call for a different explanation. The linear trend and the length of these folds suggest that they may have been caused by horizontal compression of the rocks or consolidation over deposits made by offshore bars, or that they are in some way related to buried zones of weakness, such as those considered by Fath.[3]

It seems to the writer that horizontal compression will not satisfactorily account for such structural features as the Fairport-Natoma anticline, for it is hundreds of miles from areas of pronounced folding, and there are no series of folds of equal or greater size in the areas intervening. The structural relief across the Fairport-Natoma anticline, amounting to 100 feet or more, makes it difficult to accredit the offshore bar theory highly. In the absence of exact data it may not be unjustified to assume that, in a section of 4,000 feet of strata, shale would be compacted to 80 per cent of its original volume, and that under similar pressure sandstone would remain relatively uncompacted. To form anticlines and synclines having a difference in elevation between crests and troughs of 100 feet, a sandstone lens would need to be 400 feet thick—an improbable thickness for such a migratory and shallow-water shore form as an offshore bar.

The most probable cause of the Fairport-Natoma anticline may be found in a relation to a buried tectonic line. The prominent folds in Russell county trend in a direction that is nearly identical with that of the *en échelon* fault series of northeastern Oklahoma, the "granite ridge" or Nemaha mountains, more than 100 miles to the east in Kansas, and other possibly related major structural features mentioned under the heading, "Structure in surface rocks formed by movement along deep-seated faults."

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[3] Fath, A. E.; The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey Prof. Paper 128, pp. 75-84; 1921.

Raymond C. Moore, in an unpublished study of the detailed structure of the surface beds overlying the Nemaha mountains, has found that the domes and short anticlinal folds that lie near the crest of the ridge are parallel to it, and that gentle, variable westward dips and a continuous line of steep eastward dips mark the position of the ridge. Except that the Fairport-Natoma anticline is steepest on its west instead of its east side, its structure is similar to that of the surface beds overlying the "granite ridge."

Fath discussed two principal types of relation between the deeper lines of weakness and the structure of the surface rocks—slumping of the higher beds over the minor faults produced in intermediate strata by horizontal movement along the buried lines, and conformity of the surface beds to vertical displacements along the deep-lying zones of weakness themselves. The first process should produce a series of short folds elongated at angles of about 45° to the lines of weakness in the deeper beds. This type of structure is not that of the Fairport-Natoma anticline, though it is suggestively similar to that of the northward-trending line of domes and basins in western Lincoln county near the Russell county border, which may have been so formed in part. Slumping of the surface beds over a deep-lying zone of weakness would more probably cause a long, straight anticline such as the Fairport-Natoma anticline in the higher beds, but in order to produce this anticlinal structure the fault would need to be paralleled by other near-by faults, for if isolated it would be likely to produce only a narrow monocline at the surface. Gentle tilting of the blocks between several such fault lines would form long anticlines and synclines in the higher beds; one limb, overlying the fault, dipping gently, and the other, overlying the tilted surface, relatively steeply—a form most nearly agreeing with that of the Fairport-Natoma anticline.

However, the explanation cannot be as simple as this. The east limb of the Fairport-Natoma anticline dips from 25 to 40 feet to the mile in the surface rocks, and is steeper below, but the average inclination of the beds from the crest of this anticline eastward for 30 miles to the next hypothetical large fault zone is only 10 feet to the mile; that is, the eastward dip of the surface rocks on the anticline is at least twice as great, and in the deeper beds more than ten times as great, as that which would be caused by merely regional tilting between two fault lines. This steeper dip may be due to a bending upward of the upthrown edge of the block between the faults, or to local irregularities either on the surface of the tilted block or in the beds above.

The upthrown edge of the block would probably be bent upward only if the region were under horizontal compression—a condition that seems improbable. Local irregularities in the beds above the old surface of the tilted block that might account for the steeper dip would be either a long, straight lens of sandstone lying exactly along the upthrown edge of the block, or a narrow area in which the salt beds had been partially dissolved parallel to and east of the edge of the block. Of these two possibilities, an area of leached salt beds east of the edge of the block seems the more plausible, but neither explains these steeper dips as satisfactorily as would local irregularities on the buried surface of the tilted block. A more or less curving synclinal axis east of the anticline (Plate V) is the complement of this steeper eastward dip on the side of the anticline, and such a syncline may be interpreted as the surface reflection of a buried stream valley.

This interpretation, which is in harmony with the explanation offered for the gentle unsystematic folds in Russell county, suggests three alternative explanations of the origin of the Fairport-Natoma anticline: (1) that a land surface on which valleys and ridges had been developed and which was buried beneath younger sediments was at some later time faulted; (2) that a land surface was faulted after valleys and ridges had been developed but before the overlying beds were deposited; or (3) that a land surface was faulted and afterwards valleys and ridges were developed upon it. In the first alternative the valleys would show no relation to the fault zone and erosion would not have had an opportunity to modify the upthrown edge of the buried block. In the third alternative those valleys near the fault zone would tend to be elongated either parallel or at right angles to it, and the buried fault scarp would have been cut into by erosion. Long-continued erosion after the faulting would make the second alternative essentially the same as the third.

The synclines in Russell county and its vicinity appear to follow the directions streams would take on a land surface that had been previously faulted and slightly tilted. The synclines immediately west of the two prominent north-trending folds occupy positions where consequent valleys would be expected to develop—at the foot of fault scarps—and the curving syncline east of the Fairport-Natoma anticline suggests a valley so situated as to drain the hypothetical fault scarp ridge. As would be expected under this interpretation, the synclines and anticlines in the remainder of the county show no close relation to the assumed fault scarp.

No direct evidence is available regarding the possibility that erosion modified the upthrown edge of the buried block that is assumed to have formed the Fairport-Natoma anticline, but analogy with the Nemaha mountains in eastern Kansas, upon which erosion seems to have acted before Pennsylvanian deposition, likewise suggests that in Russell county streams modified an old land surface that had been previously faulted.

The interpretation that seems most consistent with the facts is that the Fairport-Natoma anticline was formed, not by movement along a buried fault, but chiefly by consolidation of sediments over a buried fault scarp.

Probable origin of structure of Russell county. Summarizing the foregoing assumptions and conclusions, the structure in the Russell county region may possibly be explained as follows:

Block faulting or differential movements between blocks of rigid pre-Cambrian rocks capped by Ordovician or Mississippian sediments took place along preëxistent fault lines or sheer zones and exposed to erosion a surface of gentle slopes and steep fault scarps. The displacement along the faults varied from place to place, ranging from several hundred feet, as in the northwest corner of Russell county, to nearly nothing, as south of Gorham. Streams flowing on this land surface cut deeper the original depressions at the base of the fault scarps, and probably shifted backward, but did not eradicate the cliffs. Meanwhile streams developed upon and carved their channels into the tilted uplands, leaving the divides near the top of the fault scarps the most prominent features of the topography.

The sea later encroached on this old land surface and covered it with sediment. After the deepest and most irregular depressions in the sea bottom had been filled, the layers of sediments deposited conformed more or less closely to the form of the old buried surface. Later the deposits were shifted by waves and currents until the bottom of the sea became nearly horizontal; that is, a greater thickness of sediments was deposited around than upon the former hills and ridges. Occasional partial withdrawals of the sea may have permitted erosion of the sediments on the higher areas over the buried hills. With the increase in the thickness of the sediments, the lower mud deposits were continuously squeezed to a smaller volume, but the old hard rocks below the plane of unconformity underwent little or no corresponding compression. The result was nearly the same as if buried hills and ridges had been thrust upward into the overlying strata, the higher hills and ridges in the harder rocks serving to localize the bending and consequently the slight stretching and thinning of the overlying strata. Minor faults and fractures produced at the fault scarp by this settling died out in the overlying beds. Thus the deposition of thicker sediments around the higher areas on the buried surface, and the stretching, and in some places local erosion, of the overlying strata above these higher areas, might combine to account for the uniformly increasing dip of the beds downward toward the plane of unconformity.

If this theory of origin is correct, granite may or may not be encountered by wells drilled deeper on these anticlines, but hard limestone, sandstone, igneous or metamorphic rock will probably be found at much higher elevations under the crests of the folds than in the corresponding synclines.[4]

Economic Significance of Method of Origin.

If the foregoing conclusions are even approximately correct, some inferences may be made that have a direct economic bearing. The anticlinal folds formed over buried hills and ridges should become progressively steeper with increase of depth until the plane of unconformity is reached, and the effectiveness of the folds as traps for the accumulation of oil and gas should likewise increase downward until this plane is reached. The folds formed over buried scarps should develop steeper dips and sharper anticlines with increase of depth than would those formed over gentler-sloping ridges and hills. Accumulation of oil and gas in commercial quantities is more probable in an anticlinal trap immediately over a buried scarp than in the higher beds or in the smaller folds formed over gentler hills, because in differential compacting, local deformation of the sediments is likely and the faults and fractures formed increase the porosity and number of avenues for the migration of oil and escape of gas. The plane of the preëxistent major fault itself, if the unconformity lay above Paleozoic sediments, might be a path of upward migration of older oil and gas, and minor movements along it after burial would develop other stresses and fractures that might be favorable to the origin and accumulation of petroleum. Thus the chance of finding oil in the Fairport-Natoma anticline probably increases with depth, at least until the plane of the unconformity is reached.[5]

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[4] Since this report was written granite or arkose was encountered at a depth of 3,628 feet in the Producers and Refiners Oil Corporation Haise No. 1 well, NW¼ SE¼, sec. 24, T. 12 S., R. 15 W., Russell county, six miles east of the Fairport-Natoma anticline.

Structural features developed by the consolidation of sediments about sandstone lenses that lay near the surface, and by slumping at places over dissolved salt beds, would be unfavorable to the accumulation of oil and gas in all but the shallower sands. Basins or "closed" synclines, unless in part the result of deeply buried lenses of sandstone, would be a criterion of these unfavorable types of structure.

It is therefore concluded that the prominent anticlines that show steep dips and are developed more or less continuously along the persistent northward-trending lines of deformation in western Kansas are the most promising places for tests for oil and gas. The recognition of such a fold, however, by no means assures the discovery of oil, for the almost unpredictable factors—an adequate source of petroleum, suitable paths of migration, porous reservoir rock, and an impervious cover—must be combined to produce an oil field. Folds that lie along but at an angle to lines of deformation, and that are steeper on one limb than on the other, should be almost equally favorable. The gentler folds of no well-defined trend that occur at varying distances from the northward-trending lines are much less likely to yield oil. Other things being equal, the larger and the steeper-dipping of these gentler anticlines should be the more favorable for tests. Least promising of all the structural features in the Russell county region are the anticlines far from the regions of more intense deformation, which are inferred by their association with structural basins, by observations of outcrops, or by well logs, to be the result of compacting of sediments over shallow-lying sandstone lenses or of slumping of the strata into places from which beds of salt have been dissolved.

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5. Wells drilled recently suggest that an unconformity separates early and late Paleozoic sediments in Russell county and that this unconformity in the producing field is probably about 100 feet below the oil-bearing horizon. Beds yielding water or small amounts of oil or gas have been found in the 100 feet below the producing horizon in wells throughout the county, and it is possible that the lower beds may be found to yield oil on the Fairport-Natoma anticline.

PART II.

A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas.

By M. N. Bramlette.

THE correlation presented in Plate VI* is not so definite as could be desired, since cuttings from only widely separated wells were available for microscopic examination, and even the wells for which logs could be obtained in much of the area between Russell county and the eastern part of the state, where the various formations are more clearly identified, are too far apart to permit precise correlations. Correlation of the beds from Russell county northeastward to Osborn and Lincoln counties and thence southeastward to Ellsworth county is less definite than along the rest of the line, but the northerly wells were included because of the drilling activity in Lincoln county. The correctness of the correlation in the region to the north is checked by the evidence derived from the correlation of the beds between Russell county and Ellsworth county. The basis for some of the correlation lines that seem unjustified by the driller's logs will be found in the descriptions of the well cuttings. The several stratigraphic units discriminated are described below.

The attempt to make correlations from logs of wells, especially wells that are far apart, may lead to minor errors or even to complete misinterpretation. For areas where logs are numerous such misinterpretation may be avoided by tracing as far as possible thin individual beds that should be nearly equivalent stratigraphically; thicker beds or series of dominantly calcareous, arenaceous or argillaceous rock may be transgressing, and unless that fact is discovered serious errors may be made that can be corrected only by studies of collections of fossils. The surest way to avoid error in stratigraphic correlation is to preserve for examination numerous fossiliferous well cuttings, the supreme value of which should constantly be impressed upon the oil operator.

Unit 1. The first unit discriminated includes the formations above the Dakota sandstone of the Russell county region. Individual formations cannot be separated and correlated from the drillers' logs, and are generally classed as brown, blue or grey shale, and an occasional thin bed of other lithologic type.

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* Plate VI, Correlation of well records, showing tentative determinations of geologic units extending from Marion county into Russell county, will be found in pocket on inside of back cover of this bulletin.

Unit 2. The Dakota sandstone is logged as a heterogeneous series of brown sands, blue shales, red rock and gray shales, the individual beds of which cannot be correlated definitely, though the uppermost red beds, in the upper part of the formation, seem to mark a fairly constant key horizon for correlation in the region near the original producing well of Russell county. The top of the Dakota sandstone is not easily recognized in the drillers' logs, and the line marking it in the cross section is based on information obtained in the field. Cuttings from this formation show that the sand is highly variable and poorly sorted, some of it very well rounded, some angular, at some places with an admixture of argillaceous material, at others with glauconite, and commonly with much pyrite. Some of the sand beds are water-bearing. The lower part of this series possibly belongs to the Comanche (Lower Cretaceous), but the Upper and Lower Cretaceous rocks are similar lithologically and cannot be separated with confidence in well records.

Unit 3. The top of the Permian "Red Beds," or Cimarron group, is a rather distinct horizon in Russell county, and though these beds cannot be subdivided into the units recognized at the outcrop in the southern part of the state, they include units that are of value for local correlation. One unit that is of especial value is the 50-foot bed of anhydrite that occurs about 330 feet below the top of the red series in the western part of Russell county. This bed, which is found throughout Russell county and in parts of adjoining counties, affords a valuable check on subsurface structure in the region. It is logged by the drillers as lime. Another bed, measuring something less than 50 feet, occurs in this series a little more than 100 feet below the base of the 50-foot bed of anhydrite. This is logged as brown or gray or blue shale by the drillers, and an examination of a few of the cuttings shows that it probably consists of anhydrite or gypsum and gray shale. The "Red Beds" generally consist of a red siltstone and some red, fine sandstones and red shales, with interbedded green-gray rock of the same lithologic character as the associated red rock. Finely granular gypsum occurs at irregular intervals through the "Red Beds." The Cimarron is more than 600 feet thick in western Russell county, but it becomes thinner eastward and northward and disappears altogether in McPherson county. The well-log cross section suggests that some of the beds in the thick series of gray shales above the salt in McPherson county may be gray equivalents of the red Cimarron.

Unit 4. Below the red strata there is about 100 feet of material, usually logged as blue shale, consisting of gray shale and anhydrite and probably belonging to the Wellington formation. This overlies the salt beds of the lower part of the Wellington formation. The bed of rock salt included in the Wellington is variable in thickness, ranging from less than 200 feet to more than 300 feet in Russell county and adjacent regions, but thinning toward the east, in McPherson county, and disappearing in eastern McPherson county and at the western edge of Harvey county. The salt is usually recognized by the drillers, but its exact upper and lower limits are often doubtful. In places it seems to be a bed of almost pure salt; at others it includes interbedded gray and red shale and anhydrite.

Unit 5. Below the rock salt lie about 400 feet of alternating gray shale, gray anhydrite, impure dolomite and red beds, without limestone and with only a few fossils in its lower part. This series might well be classed as a part of the Wellington, though in the area to the east the base of the salt is considered the base of the Wellington. Whether these beds represent a formation that has no stratigraphic equivalent in the area to the east, or whether they are a much thicker development of the gypsiferous Pearl shale member of the Marion formation, or the nonmarine equivalents of some of the fossiliferous marine upper Permian in the region of its outcrop, has not been determined. The cross section suggests the relation last mentioned, and indicates that these anhydrite, shale and dolomite beds may be equivalents of the Marion formation and part of the Chase formation of the region to the east. The beds of anhydrite and dolomite are logged by the driller as limestones. In a few of the wells, such as the Denmark well in Lincoln county (sec. 9, T. 11 S., R. 8 W.), some thin fossiliferous limestones are interbedded with the lower part of this series, and some anhydrite occurs below the first very fossiliferous cherty limestone of the underlying unit, showing that there was an alternation of conditions in some regions.

Unit 6. The first distinctly fossiliferous marine limestone occurs at a depth of 1,915 feet in the original producing well in Russell county, the Valerius Oil and Gas Company's C. C. Oswald No. 1. The upper part of this limestone, containing crinoids, ostracods, bryozoa, a small foraminifer, and other fossils, is somewhat cherty, and at a depth of 1,950-1,970 feet the limestone is more cherty.

This unit cannot be exactly correlated with the outcropping marine Permian until more cuttings from intermediate wells have been examined, but a similar cherty, fossiliferous limestone containing an unusually large number of bryozoa occurs at apparently the same horizon in the Denmark well (sec. 9, T. 11 S., R. 8 W.), Lincoln county; in the Sheridan well (sec. 21, T. 15 S., R. 6 W.), Ellsworth county; in the Allison well (sec. 28, T. 19 S., R. 3 W.), McPherson county; and at a depth of about 260 feet in the Batt well (sec. 9, T. 19 S., R. 4 E.), Marion county. This horizon in the Batt well is apparently that of the Wreford, according to correlations made by the Kansas Geological Survey in Marion county. This cherty, very fossiliferous unit of the western region may possibly be correlated with beds that lie at a higher horizon farther east, such as the Fort Riley limestone or the Florence flint; but its relation to adjacent beds, its lithologic character, and its fossils—though all the species of Bryozoa are not identical—make its correlation with the Wreford of Marion county seem the most probable.

Unit 7. Below unit 6 in the original producing well there are about 400 feet of shales, limestones and red beds, and below these lie 450 feet of blue shale and thin layers of limestone and sand. Individual beds in this thick series cannot be certainly correlated with units recognized farther east, but the entire series would seem to be equivalent to formations extending downward from the Council Grove (Permian) through the Wabaunsee and part of the Shawnee to the Topeka limestone. Individual red beds of this series correlate well through Ellsworth, Saline and McPherson counties and check the general correlation shown on the cross section. In Marion and McPherson counties the lower part of this series, including the Scranton and Severy shale members of the Shawnee formation, is distinctly arenaceous.

Unit 8. Below unit 7, at a depth of 2,753 feet in the original producing well, the Valerius Oil and Gas Company's C. C. Oswald No. 1, begins a series of limestones and thinner beds of shale and sand that extend downward for 284 feet to the bottom of the well. These limestones are light gray to yellow brown, fossiliferous (many *Fusulina*), somewhat cherty, and at certain horizons oölitic, notably at a depth of 3,010-3,014 feet. The whole group seem to correlate with the Shawnee from the top of the Topeka limestone and the Douglas to the base of the Oread limestone. The cuttings from the oil-producing rocks are limestone and a little dark gray shale and chert, but no sand, and would seem to correlate with the Oread limestone of eastern Kansas.

Unit 9. In wells drilled below this limestone series in Ellsworth county and to the east there is an aggregate of beds of shale, sandstone and limestone 200 or 300 feet thick, which is classed as Douglas below the Oread, including the thick Lawrence shale, and there is a very considerable amount of sand in the upper part of this series corresponding to the sandy facies of the Lawrence shale at many of its outcrops. These sands are at many places water-bearing. Some beds of red shale occur in this series in Ellsworth, Saline and Russell counties, but they do not seem to persist at any definite horizon.

Unit 10. Beneath this clastic series for about 300 feet the strata, which consist largely of limestone, but include a few thin beds of shale and sand, seem to correlate with the thick Lansing and Kansas City calcareous formations of eastern Kansas. Oölitic limestone is common and is often logged by drillers as sand, as is some of the cherty limestone in these formations. *Fusulina* is seldom found in this series, and is usually represented by a small species, such as is found in this part of the Pennsylvanian section in eastern Kansas.

Unit 11. The series of shales, sandstones, red shales and thin limestones under the limestones of the Lansing and Kansas City formations may be correlated with the Marmaton and Cherokee formations. The red shales usually encountered in the lowest part of this group are much thicker than any encountered in eastern Kansas.

Unit 12. Below the Cherokee shale at many places lies a bed of cherty limestone that is considered of Mississippian age. It is generally water-bearing and in a few wells it gives showings of oil. Beneath this bed lies a series of beds of limestone, shale, dolomite and sand, the lower part of which is undoubtedly Ordovician. In the Urschell No. 4 well, in T. 21 S., R. 5 E., Marion county, the formation immediately under the Cherokee shale is a cherty dolomite and is probably Ordovician, indicating that the Mississippian has been eroded from this region, though the typical chert is found in the Batt well, in T. 19 S., R. 4 E. Well cuttings from these pre-Pennsylvanian rocks have been very commonly preserved, especially in eastern Kansas, and a stratigraphic study based on these cuttings may yield some very definite results.

ADDENDA.

After this correlation was completed, some paleontologic work was done on the faunas obtained from the cuttings. In general this work corroborated the conclusions reached by the lithologic and well-log correlation, but it developed one important difference. A very fossiliferous sample taken from a depth of 3,500 feet in the Sheridan well, in sec. 21, T. 15 S., R. 6 W., Ellsworth county, proved to be of Pennsylvanian age. If this sample is representative of the formation at 3,500 feet, it disproves the conclusion as to age arrived at in the correlation, and the very cherty horizon classed as Mississippian chert in this region would be of Pennsylvanian age. As this particular sample is very different both in lithology and in its abundant fossils from the samples above and below, and as such a horizon has not been found in this part of the section elsewhere, it seems possible that it may be a caved sample and so of no significance. All other evidence seems to favor the Mississippian age of this cherty horizon, and the writer believes that the sample is not representative. However, its value must remain an open question until more paleontologic evidence from the chert zone or from the underlying shales is obtained. Since this is an important question, any such evidence, if found, should be made known.

Some samples received from the M. M. Valerius Oil and Gas Company's Phillips well, sec. 3, T. 13 S., R. 13 W., Russell county, after the completion of this study, show that there is a series of limestones and some shales, with *Fusulina,* down to a depth of 3,135 feet that is certainly of Pennsylvanian age, and the limestone from 3,000 feet to about 3,150 feet are tentatively considered to be representative of the dominantly calcareous Lansing and Kansas City formations of eastern Kansas. A fossiliferous horizon at 3,160 feet was examined by P. V. Roundy, of the United States Geological Survey, and found to contain *Glyptopleura* sp., *Bairdia* sp., *Fusulinella* sp., *Cytherella* sp., *Endothyra?* sp., *Meekospira?* sp., and *Natacopsis* (immature) sp. He considers this fauna of early Pennsylvanian age. In this well the Pennsylvanian rocks below the main producing horizon of Russell county are thus about 200 feet thick. This is much less than the thickness of the equivalent beds in eastern Kansas which contain more coarse clastic material. No cherty horizon like that classed as Mississippian in the region to the east is present here.

The shales, red rock and thin limestones between 3,200 feet and 3,300 feet may be basal Pennsylvanian, Mississippian or Ordovician, as samples were not available for examination. Red rock of Ordovician age occurs at 3,400 feet in this well, and there is red rock in the basal Pennsylvanian east of Russell county. The red rock between 3,220 feet and 3,285 feet may represent residual or weathered material formed between Ordovician and Pennsylvanian times.

Fossils definitely of Ordovician age have been found in this well at a depth of 3,335 feet. A few samples were examined from depths of 3,465 feet to 3,554 feet that were a brown crystalline, cherty, sandy dolomite identical lithologically with the material classed as Ordovician dolomite in the region to the east.

PART III.

Fossils from Wells in Central Kansas.

By Raymond C. Moore.

General Conditions.

IN his microscopic study of cuttings from deep wells in central Kansas, Mr. Bramlette discovered a considerable number of fossils. Some of these are small fragments of shells that were so much broken up by the drill that their specific, or even their generic, identification is impossible. The cuttings also contain diminutive, even microscopic, fossils which are so small that they were not destroyed by the drill, and may be separated, practically unbroken, from the cuttings. These small fossils are the most valuable for subsurface correlation, because in most well cuttings they are much more abundant than the larger fossils; because they are, in general, sufficiently complete to permit rather precise identification; and because most of them are as good stratigraphic markers as the large fossils. Unfortunately, however, although most of the larger fossils in the rocks of Kansas have been studied and described, the microscopic fossils are not yet generally known.

An examination of the cuttings from wells in Russell, Lincoln, Ellsworth, McPherson and Marion counties showed the occurrence in several wells of a cherty limestone containing many microörganisms. In the more westerly wells this limestone was everywhere found at about the same stratigraphic distance below the base of the Permian salt beds. In the wells in McPherson and Marion counties, where there are no salt beds, the most fossiliferous zone is found in the upper part of the stratigraphic section, and evidently corresponds to one of the cherty limestones of the marine Permian which crop out farther east. The fossils obtained from the cuttings were studied in order to ascertain, if possible, whether the fossiliferous zone in the different wells belongs to one formation, and to identify that formation. The similar position of the fossiliferous zone as recorded in the logs, especially the logs of wells in Russell, Lincoln and Ellsworth counties, strongly indicates stratigraphic equivalence, and the general similarity of the faunas, which are composed of foraminifers, bryozoans and ostracods, is suggestive, though not conclusive, of equivalence, for these are the classes of organisms that would normally be preserved in well cuttings. However, as other comparable lots of small fossils are not found in beds above and below the fossiliferous zone, and as the fossils in the several wells occur in similar rock, as the stratigraphic position of the fossiliferous zone is about the same in all the wells, and as the general composition of the faunas is identical, it may reasonably be assumed that the fossiliferous bed in each of these wells lies at the same stratigraphic horizon. If so, it is a valuable marker in stratigraphic correlation and in the determination of structure. Even if one or another of the different kinds of microscopic fossils is not found in all the collections, and even if there is some variation in species, they may still represent a single formation, for the small amount of cuttings preserved from any one well may not adequately represent the formation as a whole, and a certain amount of variation in genera and species may be expected from place to place within a single formation.

THE OSWALD WELL, RUSSELL COUNTY.

The fossils listed below come from a depth of 1900-1920 feet in the Stearns-Streeter Company's No. 1 Ed Oswald well, in the southeast corner of the southwest quarter of the southwest quarter of sec. 8, T. 12 S., R. 15 W., Russell county:

Fauna from 1900-1920 feet in the Stearns-Streeter Ed. Oswald well, Russell county, Kansas.

- Bryozoa:
  - Acanthocladia sp. A.
  - Acanthocladia sp. B.
  - Fenestella sp.
  - Batostomella? sp.
  - Rhombopora sp. A.
  - Rhombopora sp. B.
    aff. R. lepidodendroidea.
  - Rhombopora? sp.
  - New genus aff. Leioclema.
- Ostracoda:
  - Bythocypris sp. A.
  - Bairdia sp. A.
  - Bairdia sp. B.

This fauna shows a predominance of ramose bryozoans, all very well preserved except *Fenestella*, which is represented by a single fragment. The specimens of *Acanthocladia* are not like those of any species yet described, and probably represent new species. There are specimens of two distinct types of *Rhombopora*, the larger of which resembles closely specimens of *R. lepidodendroidea* identified from upper Pennsylvanian and lower Permian formations in Kansas. The specimen listed as a new genus is a striking little fossil that shows the large, rounded, rather well-spaced zoöecia of *Leioclema* with intervening angular mesopores opening on the surface, but this, unlike that genus, has a prominent tubular axial canal, somewhat like that in *Rhabdomeson*. Among the ostracods *Bairdia* is strongly predominant, most of the specimens from the Stearns-Streeter well belonging to a single species, which resembles *B. beedei*, but is smaller and somewhat longer than that form. A single specimen belonging to the genus *Bythocypris* was found. All the ostracods are smooth-shelled.

THE THURMAN WELL, LINCOLN COUNTY.

Cherty limestone at a depth of 1,382 feet in the Thurman well, sec. 25, T. 12 S., R. 10 W., near the town of Sylvan Grove, in Lincoln county, yielded a collection of small fossils that is somewhat larger and more varied than that obtained from the Stearns-Streeter Ed Oswald well. The fauna is made up nearly equally of foraminifera, bryozoans and ostracods.

Fauna from 1,382 feet in the Thurman well, Lincoln county, Kansas.

- Foraminifera:
  - Tetrataxis sp. A.
  - Tetrataxis sp. B.
  - Fusulina sp. A.
  - Fusulina sp. B.
- Bryozoa:
  - Acanthocladia? sp. aff. A. sp. B., Oswald well.
  - Fenestella sp. ? aff. F. inaequalis Ulrich.
  - Fenestella sp. aff. F. limbata Foerste.
  - Fenestella sp. A.
  - Fenestella sp. B.
  - Fenestella sp.
  - Polypora sp.
  - Septopora sp. A. aff. S. biserialis (Swallow).
  - Septopora sp.
- Worm tube:
  - Spirorbis sp.
- Ostracoda:
  - Bythocypris sp. A.
  - Bairdia sp. A.
  - Bairdia sp. C.
  - Bairdia sp. D.
  - Bairdia sp. E.
  - Cytherella? sp.
- Echinodermata:
  - Crinoid stems.

The Thurman fauna is marked first by the presence and relative abundance of foraminifera, and second by the dominance of the fenestelloids among the bryozoans. The number and the variety of ostracods is greater than in the Stearns-Streeter Ed Oswald well.

The minute shells identified as *Tetrataxis* are very well preserved and under the microscope show clearly the arrangement of the chambers that make the low cone typical of a member of the *Valvulina* group. The base of the cone-shaped shell is flat or concave and is marked by the irregularly stellate opening to the interior. Species A, which is generally the more abundant, is about 0.5 mm. in diameter or less; species B has a diameter across the base of the cone of about 1.4 mm. and is more strongly concave beneath. *Fusulina* sp. A. is a moderately robust species, about 4 mm. long and 1.5 mm. in diameter. Its internal structure has been studied, but shows no features that definitely distinguish it from other species of *Fusulina*. *Fusulina* sp. B. is a diminutive species, which is apparently distinct from A.

Among the bryozoans, the genus *Fenestella* predominates, being represented by four or five species. Specific identification of these forms is difficult, because much of the material is fragmentary and because the bryozoans from this horizon have not been thoroughly studied. *Polypora* and *Septopora* are also represented.

A simple, moderately large and well-preserved worm tube belonging to the genus *Spirorbis*, with flat base, low spiral coil, and spire having a diameter at base of 1.8 mm., was obtained from the Thurman well.

There are several types of ostracods, but the smooth, unsymmetrical-shelled *Bairdia* predominates. The form listed as species A appears to be the same as one of the types from the Oswald well. Some of the species, especially *Bairdia* sp. C, which is the smallest of the group, measuring 0.6 to 0.7 mm. in length by 0.4 mm. in height, are represented by a number of excellently preserved specimens.

THE SHERIDAN WELL, ELLSWORTH COUNTY.

The Sheridan well, drilled in sec. 21, T. 15 S., R. 6 W., southeast of Carneiro, Ellsworth county, has yielded a micro-fauna from a depth of 1,250 feet, which appears to represent the fossiliferous horizon already noted. The species distinguished are as follows:

Fauna from 1,250 feet in the Sheridan well, Ellsworth county, Kansas.

- Foraminifera:
  - Tetrataxis sp. A.
  - Fusulina sp. B?
  - Fusulina sp. C.
- Bryozoa:
  - Rhombopora sp. cf. R. lepidodendroidea.
  - Rhombopora sp.
  - Batostomella? sp.
  - Acanthocladia sp. A?
  - Fenestella sp. aff. F. conradi-compactilis Condra.
  - Fenestella sp. A.
  - Fenestella sp. B?
  - Fenestella sp. C.
  - Fenestella sp. D.
  - Fenestella sp. E.
  - Polypora sp.
  - Septopora? sp.
- Ostracoda:
  - Bythocypris sp. aff. sp. A.
  - Bairdia sp. A.
  - Bairdia sp. C.
  - Bairdia sp. F.
  - Kirkbya sp. A.
  - Kirkbya sp. B.
- Echinodermata:
  - Crinoid stem.
  - Archeocidaris sp. A.
  - Archeocidaris sp. B.

This fauna is similar in general composition to those already listed, and a number of the species are identical, but it includes some interesting additional species. The most striking are the beautifully and delicately marked undescribed species of *Kirkbya*. *Archeocidaris* is represented by coarse and very fine spines. Among the rest, the genus *Fenestella* is dominant among the bryozoans, and there are numerous specimens of *Bairdia,* especially the rather distinctive little form here called species C.

The Allison Well, McPherson County.

At a depth of 980-1,005 feet in the Allison well, in sec. 27, T. 19 S., R. 4 W., there is a cherty limestone containing numerous very small fossils which appear to lie at a stratigraphic horizon found at greater depths in wells farther west. The fauna obtained from the cuttings is as follows:

Fauna from the Allison well, McPherson county, Kansas.

- Foraminifera:
  - Nodosinella sp. A.
  - Tetrataxis sp. A.
  - Tetrataxis sp. B.
  - Fusulina sp. B.
- Bryozoa:
  - Rhombopora sp.
  - Fenestella sp.
    - cf. F. conradi-compactilis Condra.
  - Fenestella sp. A.
  - Fenestella sp. C.
  - Fenestella sp. F.
  - Fenestella sp.
  - Polypora sp. A.
  - Polypora sp.
  - Septopora sp. A.
  - Septopora sp. B.
- Ostracoda:
  - Bythocypris sp. A.
  - Bairdia sp. C.
  - Bairdia sp. E.
  - Bairdia sp. G.
- Echinodermata:
  - Crinoid stems.

In addition to the two species of *Tetrataxis* and the small *Fusulina* which are found in other wells, the collection from the McPherson well contains a number of small nodose uniserial foraminifers which appear to belong in the genus *Nodosinella.* This type of fossil protozoan has been found at several places elsewhere in Permian and Pennsylvanian rocks, but not in Kansas.

Fenestella is the most abundant genus of Bryozoa in this lot, as well as in the collection from the Sheridan well, and three of the species listed appear to be common to both lots. The fragments of *Polypora* and *Septopora* are also closely similar to species of these genera found in other wells, but the specimens are so incomplete that they cannot be referred to the same species with certainty.

The ostracods, which are relatively numerous, belong to the smooth types, *Bythocypris* and *Bairdia.* The small species of *Bairdia* listed as species C, which is found in most of these collections, is the most abundant.

The Batt Well, Marion County.

A fairly complete series of cuttings from the Argus Oil Company's Batt No. 1 well in sec. 9, T. 19 S., R. 4 E., Marion county, which were made available for microscopic examination, yielded a fairly prolific micro-fauna from a cherty limestone that lay at a depth of 265 to 275 feet. As this well is much farther east than those already mentioned, the cherty limestone in it might be expected to lie nearer the surface. The fauna identified from the cuttings at 265-275 feet in the Batt well contains the following species:

Fauna from 265 feet in the Batt well, Marion county, Kansas.

- Foraminifera:
  - Tetrataxis sp. A.
  - Tetrataxis sp. B.
  - Fusulina sp. B.
- Bryozoa:
  - Rhombopora sp A?
  - Rhombopora sp. C.
  - Rhombopora sp. D.
  - Rhombopora sp. E.
  - Streblotrypa sp. A.
  - Streblotrypa sp. B.
  - Cystodictya sp. A.
  - Cystodictya sp. B.
  - Acanthocladia sp. A?
  - Acanthocladia sp. C.
  - Thamniscus sp. A.
  - Fenestella sp.
    - cf. F. conradi-compactilis Condra.
  - Fenestella sp. F.
  - Fenestella sp. G.
  - Polypora sp.
  - Polypora sp.
  - Polypora sp.
  - Septopora sp.
  - Acanthoclema? sp.
- Ostracoda:
  - Bairdia sp. A.
- Echinodermata:
  - Crinoid stems.
  - Archeocidaris sp.

The number and the variety of the bryozoans in this lot are its most noteworthy feature. Associated with types found in collections obtained from wells to the west are several new genera, among them *Streblotrypa, Cystodictya* and *Thamniscus*. The character of the Foraminifera, the occurrence of *Bairdia* sp. A as a representative of the ostracods, and the composition of the bryozoan division of the fauna, indicate the probable equivalence of this fauna to those already described. A fairly large content of *Rhombopora* is suggestive of the fauna found in the Oswald well; the numerous fenestelloids relate it to the collections made in McPherson and Ellsworth counties.

Correlation.

Because of the similar composition of the faunas, the similar place of their occurrence in the well sections, the lithologic similarity of the beds containing them, and the apparent absence of like fossiliferous beds near by, it seems probable that all of the lots of fossils listed above belong to a single fossiliferous zone. There are, of course, a number of more or less fossiliferous zones in the upper Pennsylvanian - lower Permian section, but only a few notably cherty formations. As the fossil-bearing cherty rock in the wells is the uppermost rock of this character, its reference to the part of the Permian section that includes the Florence and Fort Riley formations is at once suggested, though a comparison of the available well records indicates that it may be the equivalent of the flinty Wreford limestone. Several fairly large collections of fossils taken from the outcrops of the Florence, Fort Riley, Wreford and adjacent formations were examined and fossiliferous fragments of these rocks were broken up in a search for microscopic organisms similar to those obtained from the well cuttings. Fragments of the Fort Riley, Florence and some other formations that showed numerous fenestelloid and other bryozoans on the surface yielded more or less broken bryozoan material, but the ground-up rock did not contain the foraminifers and ostracods that are characteristic of this horizon in the well cuttings. However, a small piece of Wreford limestone, which happened not to be a cherty fragment, contained the following species:

Fauna from crushed fragment of Wreford limestone from near Strong City, Chase county.

- Foraminifera:
  - Nodosinella sp.
  - Valvulina (Tetrataxis?) sp. aff. V. bulloides Brady.
  - Fusulina sp. B.?
- Bryozoa:
  - Rhombopora sp.
  - Fistulipora sp.
  - Fenestella sp. B.?
  - Fenestella sp.
  - Polypora? sp.
  - Septopora sp.
- Gastropoda:
  - Murchisonia? sp.
  - Small species aff. Bulimorpha.
- Ostracoda:
  - Bairdia sp. A.
  - Bairdia sp. C.
  - Bairdia sp.
  - Kirkbya sp. B.
- Echinodermata:
  - Crinoid fragments.
  - Archeocidaris sp.

Though it doubtless affords a very incomplete representation of the minute fossils in the Wreford formation, this small lot shows obvious similarities to lots obtained from the well cuttings. The *Nodosinella* closely resembles the forms referred to this genus from the well in McPherson county. The species of *Fusulina* is small and appears to correspond to species B of the well collections. The specimens from the Wreford formation called *Valvulina sp. aff. V. bulloides* are different from the species of *Tetrataxis* in the cuttings, but although they are here placed in the broadly inclusive genus *Valvulina*, these shells may belong in the subgenus *Tetrataxis.*

The bryozoans of the Wreford suggest in general corresponding elements in the collections made from the wells, but the specimens are not sufficiently complete to permit detailed comparison.

Among the ostracods are species of *Bairdia* that are apparently identical with forms obtained from the wells, and also a good specimen of *Kirkbya,* which is the same as *Kirkbya* sp. B. from the Sheridan well, in Ellsworth county.

It appears that the fossiliferous zone described represents the

Wreford limestone, and the persistence of the zone to the west, coupled with its rather distinctive fauna, lithology, and position in the section, indicates that it may be used readily as a key horizon in subsurface studies—a much more definite and reliable horizon than the base of the salt, the base of the red beds, or other beds that are less readily identified with certainty and that may differ in stratigraphic position in different places.

From other horizons in the deep wells of central and western Kansas small fossils, especially *Fusulina,* have been obtained. Examinations recently made at the outcrop of the Pennsylvanian rocks in Kansas and a study of well cuttings show that this genus extends downward at least to the Fort Scott limestone, at the base of the Marmaton formation. *Fusulina* obtained from a depth of 3,905 feet in the Whiteside well, in sec. 2, T. 24 S., R. 23 W., Ford county, indicates the presence of Pennsylvanian sediments at least to that depth in that well. In Russell county and adjacent parts of west-central Kansas, Pennsylvanian fossils have been obtained at intervals to the bottom of the deepest wells yet drilled. The specific variation in *Fusulina* and the accompanying stratigraphic distribution of the species of that genus have not been fully investigated. Opportunity for obtaining valuable aid in subsurface work is here evident.

Notes on Other Fossils from Kansas Wells.

During the recent examination of drill cuttings from Kansas wells the following occurrences of fossils were noted in addition to those described above. Most of these have not yet been carefully studied.

In the Batt well, in sec. 9, T. 19 S., R. 4 E., Marion county, large *Fusulina* were found at a depth of 1,240-1,260 feet; numerous rather large *Fusulina* at 1,500, and 1,515-1,525 feet; and *Fusulina* sp. at 2,300 feet. Thin sections were made of these and other specimens of *Fusulina* from wells, but the several species have not been satisfactorily differentiated.

A large and a small species of *Fusulina* were found in cuttings obtained at depths of 1,080-1,105 feet in the Urschel well, in sec. 16, T. 21 S., R. 5 E., Marion county.

The Sheridan well, in sec. 21, T. 15 S., R. 6 W., showed *Fusulina* in cuttings from 1,500 feet, from 1,700 feet, from 2,100 feet (two species), and from 2,300 feet.

Drillings from the Schubert well, a shallow well drilled near Bonner Springs, in Leavenworth county, show, in a limestone at depths of 67-73 feet that probably belongs in the Kansas City formation, specimens of *Bythocypris* sp., *Macrocypris* sp., *Bairdia* (a very minute species and a larger one), and an ostracode (new genus?) belonging to Beyrichiacea.

Drillings from the Phillips well, in sec. 3, T. 13 S., R. 13 W., Russell county, show a limestone at a depth of 1,981 feet that contains numerous small foraminifers, mostly of the types of *Valvulina* and *Globigerina*.

In the Stearns-Streeter Company's No. 1 Ed Oswald well, Russell county, a sample taken from a depth of 1,925 feet, just below the horizon of the bryozoan-ostracod fauna already described, contains *Tetrataxis* sp. B. and *Bairdia* sp. A. Samples from a depth of 1,985-2,010 feet contain *Valvulina bulloides* Brady?, *Fusulina* sp., *Murchisonia?* sp., *Macrocypris?* sp., *Bythocypris* sp., and *Bairdia* sp. A. A large species of *Fusulina* occurs rather abundantly at a depth of 2,753-2,795 feet in this well and also at a depth of 2,875-2,880 feet.

A sample of oölitic limestone in the producing zone of the discovery well, the M. M. Valerius Company's No. 1 C. E. Oswald well, taken from a depth of 3,010-3,014 feet, was ground to a thin section that showed a variety of small Foraminifera, *Globigerina*, *Nodosellina* and other forms in the centers of the grains of oölite. These grains are irregular in size and shape and show well-defined radial structure in their outer parts—the parts surrounding the central granules, most of which appear to consist of fragments of fossils. A small gastropod of the *Sphærodoma* type was shown in the thin section. It should be easy to identify this horizon from similar samples obtained from other wells.

ADDENDA.

Under date of April 3, 1925, P. V. Roundy made the following report on cuttings from the Phillips No. 1 well, sec. 3, T. 13 S., R. 13 W.:

All cuttings represent beds of Pennsylvanian age except possibly the cuttings from 3,170. The cuttings from 2,800 feet to 3,145 do not contain sufficient evidence to place them within any definite subdivisions of the Pennsylvanian.

The cuttings from 3,160 feet have an abundant fauna. The Ostracoda and Foraminifera represent a fauna that I have found only in beds of Pottsville age. It is possible in the present state of our knowledge of these forms that this fauna *may* occur in beds a little younger than Pottsville, but I do not think it probable. The mollusks, of which there are many, are all minute in size; many appear to be immature, and some probably are mature. These forms, Doctor Girty considers, are more apt to belong in a fauna of Pottsville age than in a younger fauna. The only objection to placing this fauna as of Pottsville age is the lack of known outcrop beds of that age in Kansas. However, since these fossils come from underground beds, so far geographically from the surface exposures of the lowest Pennsylvanian beds in Kansas, I feel that this factor should have little weight.

The cuttings from 3,170 feet have only three species, two of which are doubtfully identified and might represent either Mississippian or Pennsylvanian beds, and the third species, a single specimen, known only from the Pennsylvanian, is very abundant in the cuttings from 3,160, and might have actually slumped in the well from that horizon when the sample from 3,170 was taken by the driller.

A faunal list is given below:

2800. Fusulina inconspicua? Crinoid stem segments.
2815. Fusulina inconspicua? Crinoid stem segments.
——. Bairdia n. sp.
2825. Fusulina sp.; crinoid stem segments.
——. Bairdia sp.
2835. Nothing determinable.
2856. Fusulina sp.; indet. brachiopod.
2930. Bairdia sp.
3000. Crinoidal fragments; bryozoan fragment.
3020. Fusulina sp.; crinoidal fragments; Rhombopora? sp.; brachiopod fragment; Productus spine.
3030. Crinoid stem fragment; Productus spine.
3055. Fusulina sp.
3060. Fusulina sp.
3100. Fusulina sp.
3115. Fusulina; spine fragment.
3145. Immature cephalopod; Cytherella sp.
3160. Endothyra? sp.; Fusulinella n. sp.; Fusulina sp; Aclisina 2 sp.; Bulimorpha? sp.; Meekospira sp.; Pleurotomaria? sp.; Holopea? sp.; Naticopsis sp.; Nucula sp.; Pteria sp.; Astartella? sp.; Bairdia 2 sp.; Glyptopleura healdi n. sp.; Amphissites symmetricus n. sp.; Sansabella? n. sp.; Paraparchites sp.
3170. Meekospira sp.; Batostomella? sp.; Fusulinella sp.

A well known as Whiteside No. 1, drilled in the NW corner SW¼, sec. 2, T. 24 S., R. 23 W., Hodgeman county, Kansas, has contributed some definite information regarding the age of and the faunas carried by certain formations in western Kansas. The cuttings were studied by P. V. Roundy, who has made the following determinations:

3640-3650.	Imperfect gastropod, probably Pleurotomaria sp.
	Productus spine fragments.
	Echinoid spine fragment.
	Minute pelecypod, probably a Nucula.
	Cytherella n. sp.
	Hollina n. sp.
	Amphissites centronatus var.
	Amphisites n. sp.
3240.	Lingula sp. fragment.
3650–3665.	Fusulinella? sp.
	Hollina sp.
	Cytherella n. sp.
	Amphissites n. sp.
	Productus spines.
3743.	Bairdia, 2 species.
	Fusulina sp.
	Productus spines.
3750–3756.	Fusulina sp.
	Productus spines.
3822.	Ambocoelia sp.
3810.	Bairdia sp.
	Fusulinella sp.
	Fusulina sp.
3870.	Ostracod (new? genus).
3905.	Fusulina sp. (Very abundant.)
3935.	Fusulinella sp. (These look as if they were water-worked.)
3980.	Polygnathus n. sp.
3980–3990.	Bairdia of B. beedei var.
	Fragment Fusulina. (Certainly not water-worn.)
3993.	Fusulina sp.
	Composita? sp.
4000.	Endothyra sp. (This form, although distinct from the Mississippian E. baileyi, is much closer to it than to the Endothyras found by Mr. Roundy in the Pennsylvanian.)
	Composita? sp.

It will be noted that the evidence of Mississippian age is not conclusive, but there can be no question about the Pennsylvanian age of the strata to a depth of 3,993 feet. As the well was carried to 4,055 feet, and as there was abrupt change in the type of rock at 4,010 feet, it is quite possible that the lower 45 feet are Mississippian or even older rocks.

QE
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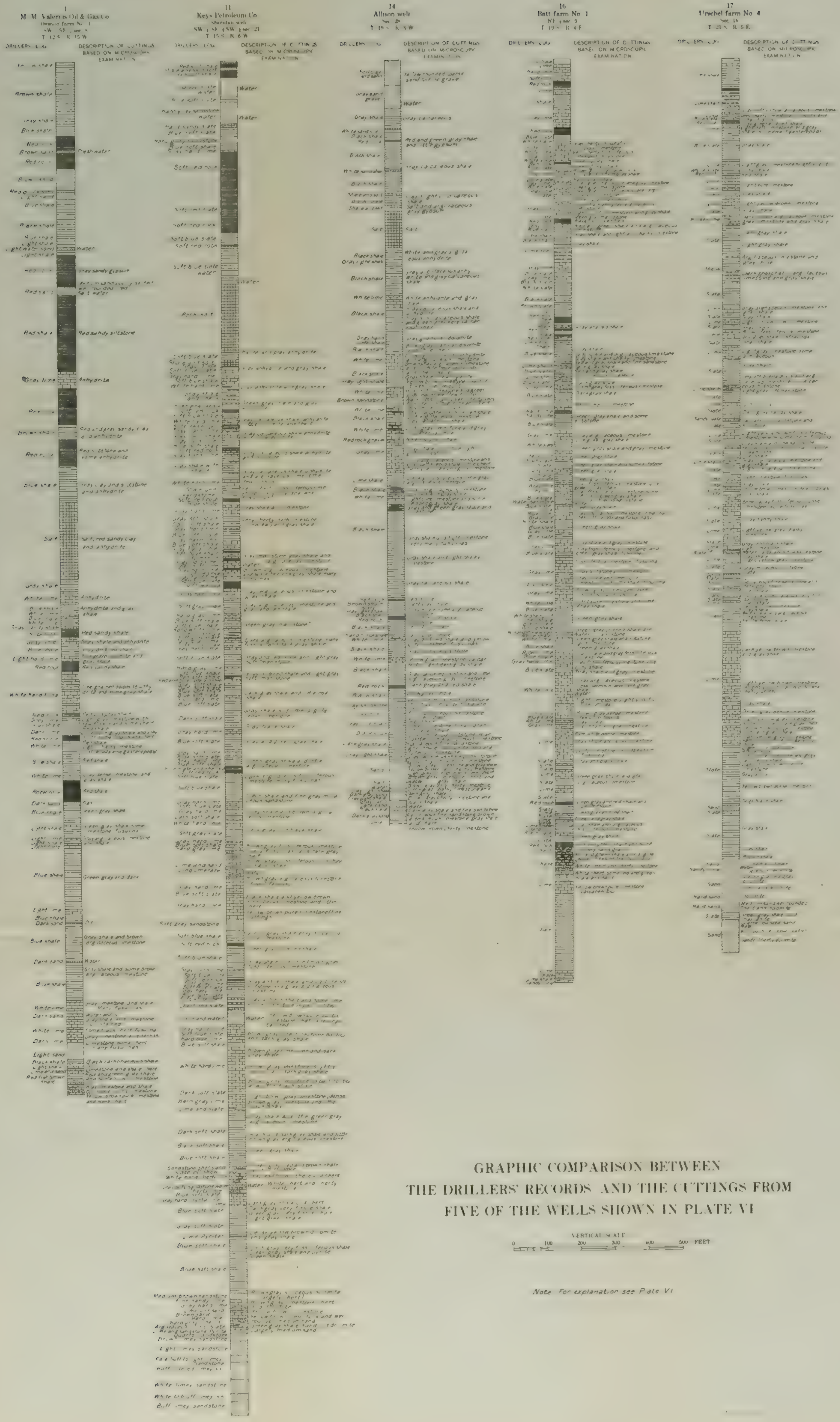
STATE GEOLOGICAL SURVEY OF KANSAS
IN COOPERATION WITH
U S GEOLOGICAL SURVEY

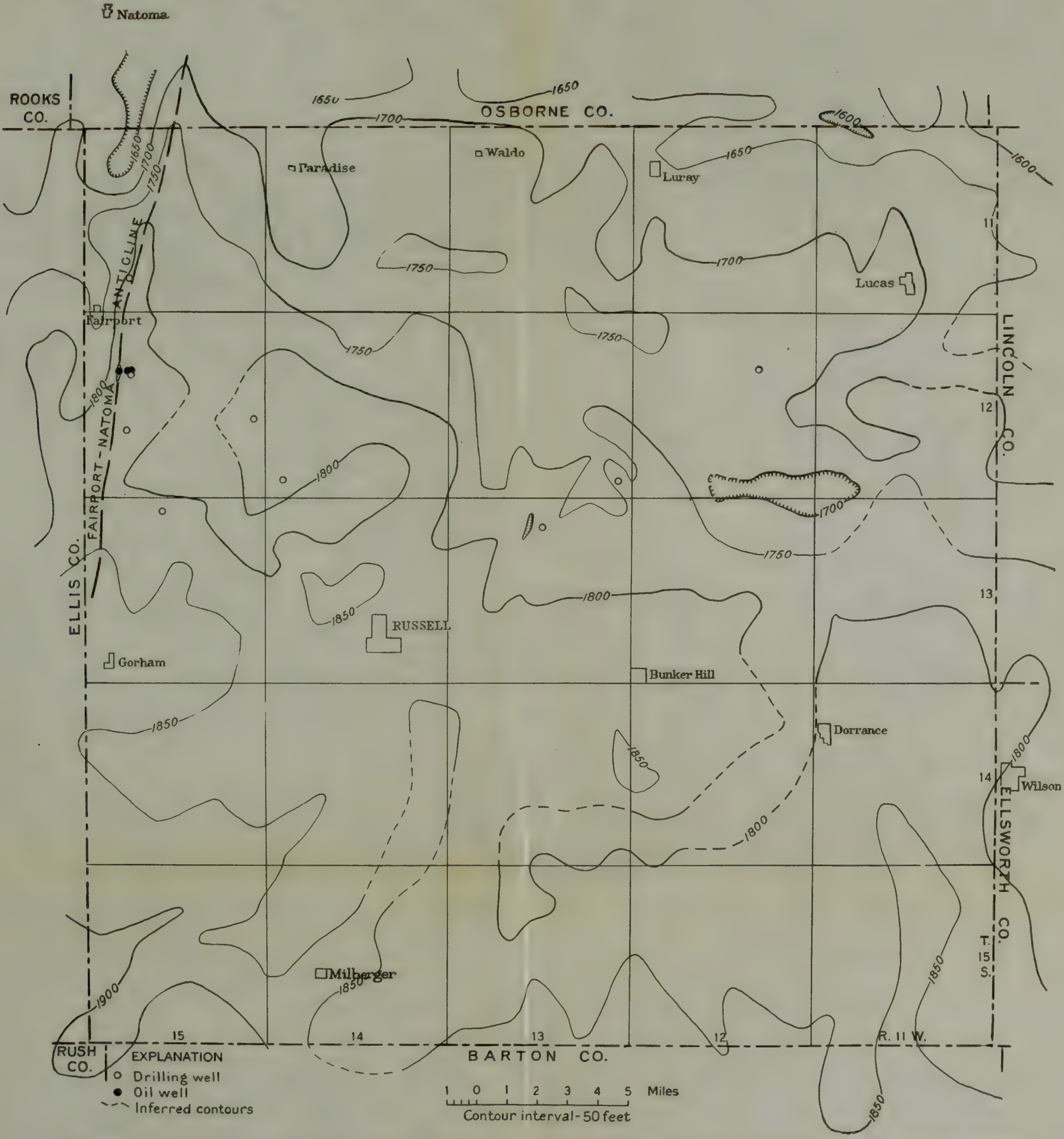

1
M. M. Valerius Oil & Gas Co
Oswald farm No. 1
SW. SE. sec. 8
T. 12 S. R. 15 W.
DRILLERS' LOG
DESCRIPTION OF CUTTINGS BASED ON MICROSCOPIC EXAMINATION
11
Keys Petroleum Co
Sheridan well
SW. ¼ SE. ¼ SW. ¼ sec. 21
T. 15 S. R. 6 W.
DRILLERS' LOG
DESCRIPTION OF CUTTINGS BASED ON MICROSCOPIC EXAMINATION
14
Allison well
Sec. 26
T. 19 S. R. 3 W.
DRILLERS' LOG
DESCRIPTION OF CUTTINGS BASED ON MICROSCOPIC EXAMINATION
16
Batt farm No. 1
NE. ¼ sec. 9
T. 19 S. R. 4 E.
DRILLERS' LOG
DESCRIPTION OF CUTTINGS BASED ON MICROSCOPIC EXAMINATION
17
Urschel farm No. 4
Sec. 16
T. 21 S. R. 5 E.
DRILLERS' LOG
DESCRIPTION OF CUTTINGS BASED ON MICROSCOPIC EXAMINATION

GRAPHIC COMPARISON BETWEEN
THE DRILLERS' RECORDS AND THE CUTTINGS FROM
FIVE OF THE WELLS SHOWN IN PLATE VI

VERTICAL SCALE
0 100 200 300 400 500 FEET

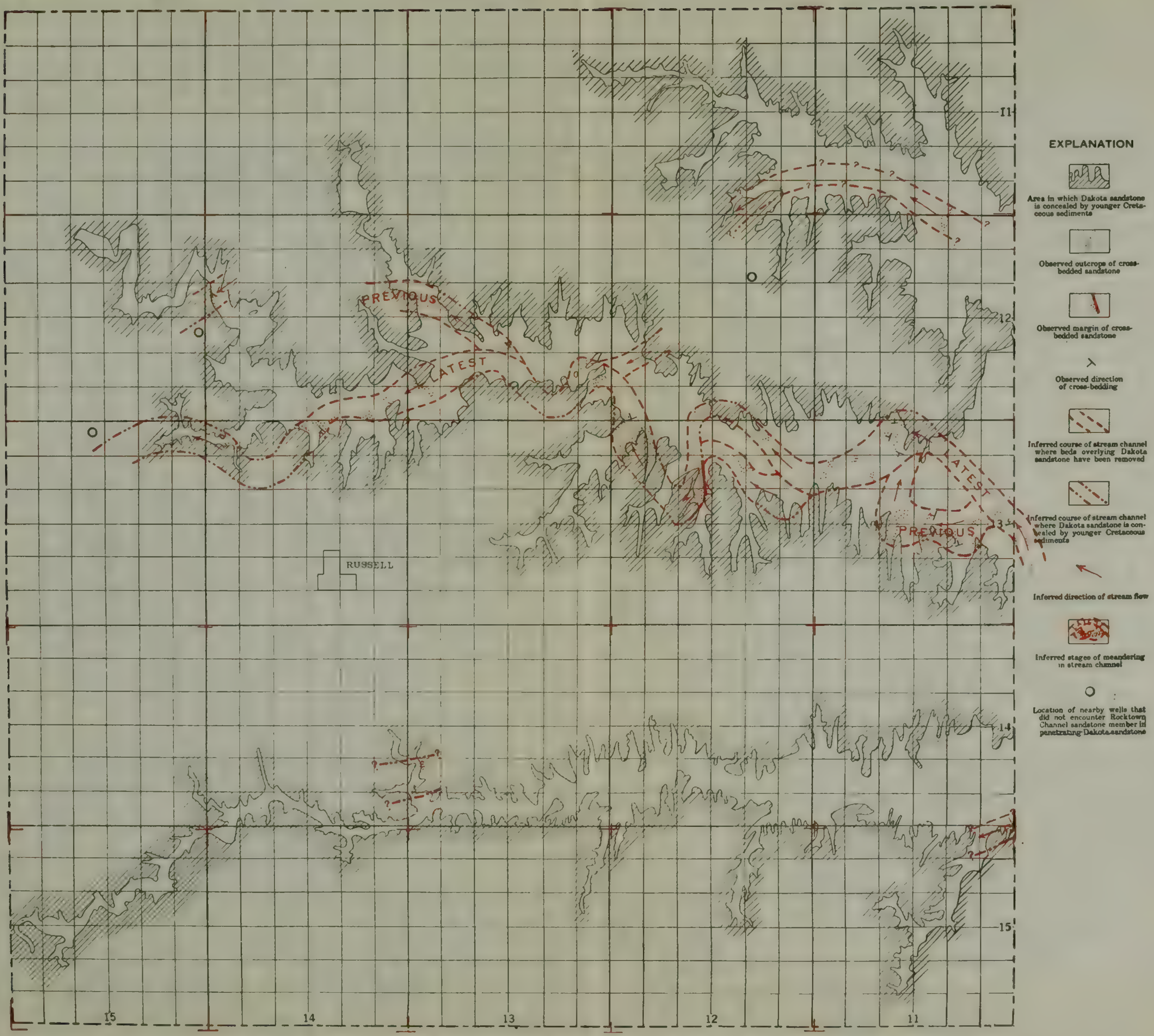
Note. For explanation see Plate VI

PLATE IV.

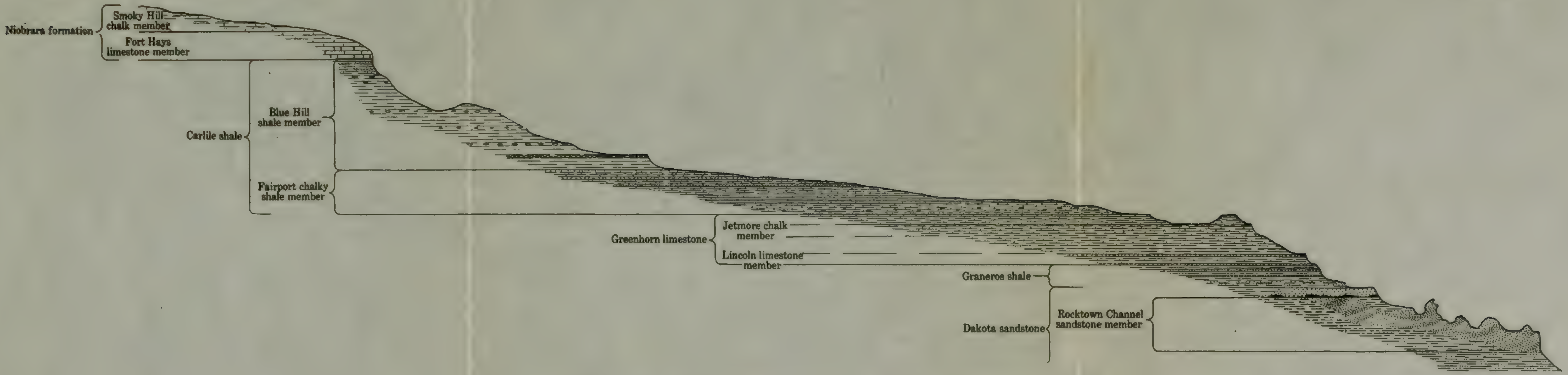


Generalized structural contour map of Russell county, Kansas. Elevations on upper surface of Greenhorn limestone—the top of the "fence-post limestone."

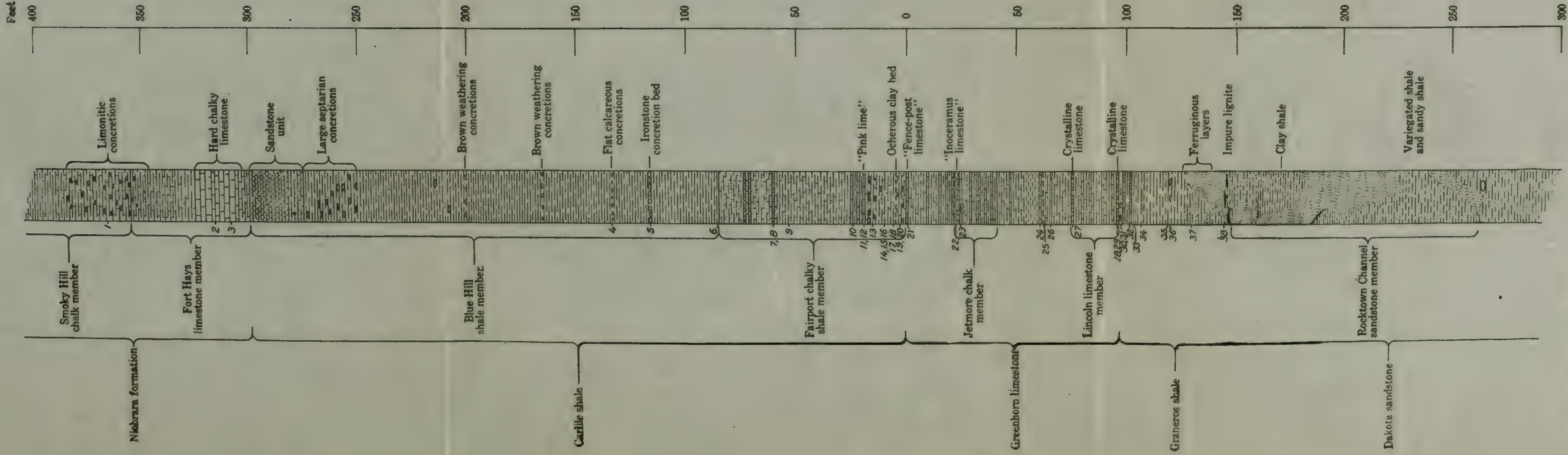
10-6048


EXPLANATION
Area in which Dakota sandstone is concealed by younger Cretaceous sediments
Observed outcrops of cross-bedded sandstone
Observed margin of cross-bedded sandstone
Observed direction of cross-bedding
Inferred course of stream channel where beds overlying Dakota sandstone have been removed
Inferred course of stream channel where Dakota sandstone is concealed by younger Cretaceous sediments
Inferred direction of stream flow
Inferred stages of meandering in stream channel
Location of nearby wells that did not encounter Rocktown Channel sandstone member in penetrating Dakota sandstone
PREVIOUS
LATEST
LATEST
PREVIOUS
RUSSELL
11
12
13
14
15
15
14
13
12
11

Approximate location in the Dakota area of Russell county of meander belt of stream and tributaries (?) that deposited the Rocktown channel sandstone member of the Dakota sandstone.

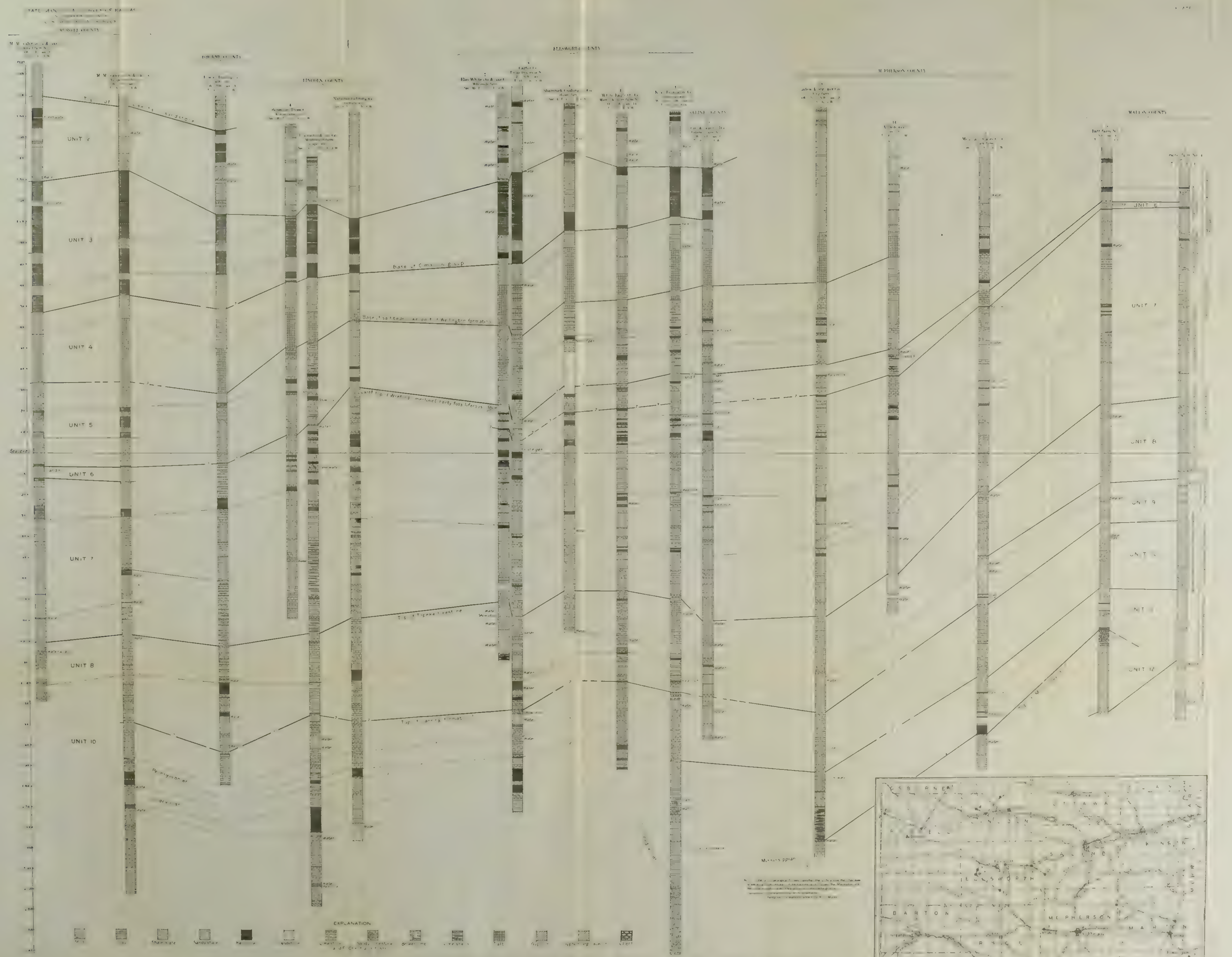


A. Idealized profile through the Cretaceous strata of Russell county, Kansas.

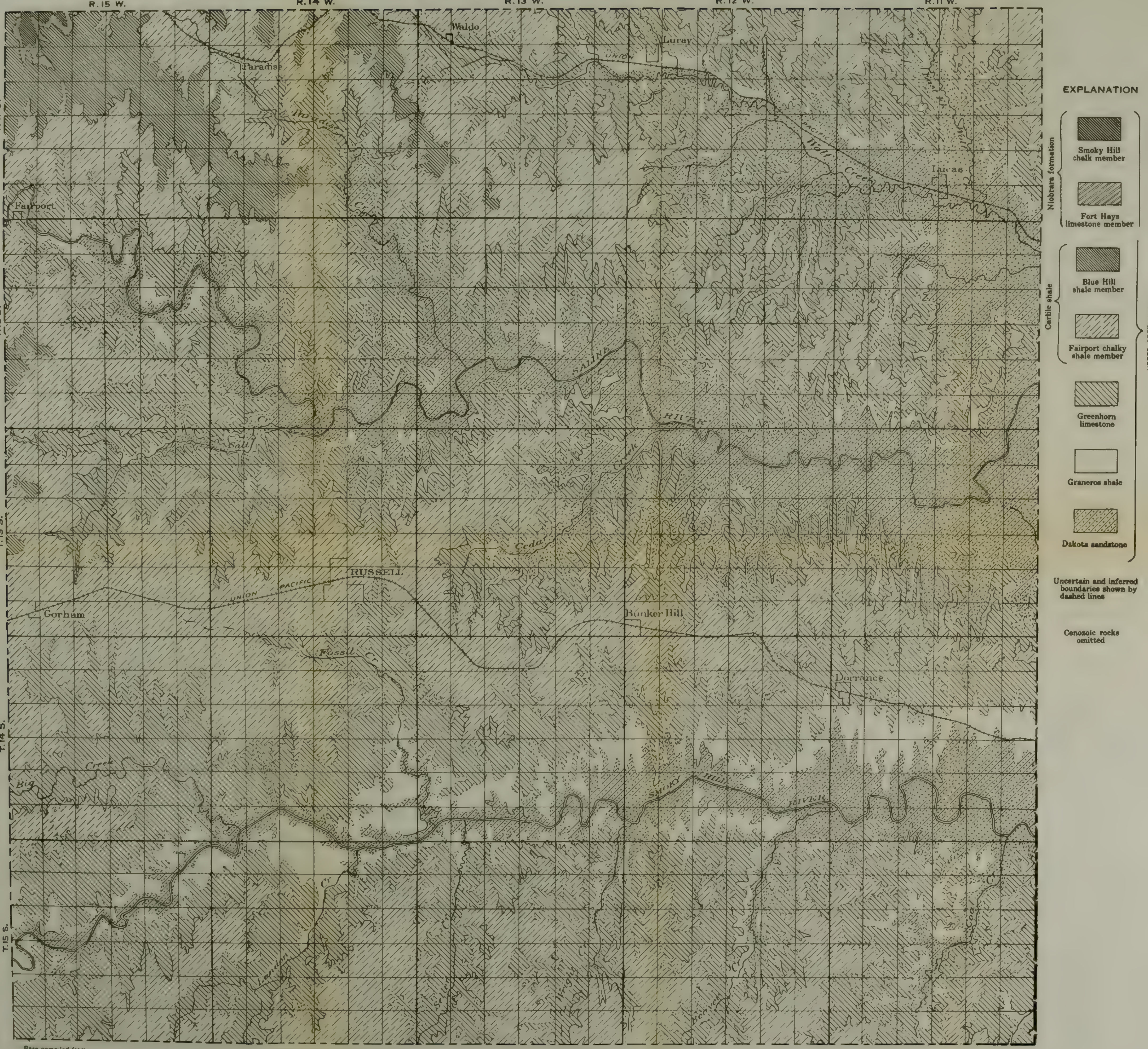


B. Generalized columnar section of the rocks exposed in Russell county, Kansas. Numbers 1 to 38 show stratigraphic position of fossil collections.

10-6048



CORRELATION OF WELL RECORDS, SHOWING TENTATIVE DETERMINATIONS OF GEOLOGIC UNITS EXTENDING FROM MARION COUNTY INTO RUSSELL COUNTY, KANSAS



Base compiled from
U S Geological Survey
topographic maps

RECONNAISSANCE GEOLOGIC MAP OF RUSSELL COUNTY, KANSAS

By W. W. Rubey and N. W. Bass

Scale $\frac{1}{125,000}$

1 0 1 2 3 4 6 6 Miles

10-6048

MESOZOIC FOSSILS.

Identified by J. B. Reeside, Jr.

FORMATION.	NIOBRARA.			CARLILE.																	GREENHORN.									GRANEROS.								
MEMBERS.	Smoky Hill.	Ft. Hays.		Blue Hill.			Fairport.															Jetmore.					Lincoln.											
Numbers of fossil collections, arranged in stratigraphic order. (Exact position shown on Plate II.)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Acanthoceras sp. indeterminable							?																															
Anchura sp				?																																		
Anisomyon n. sp																															X							
Baculites gracilis Shumard													?									X		X		?												
Callista tenuis Hall and Meek																																	X		X	X	X	X
Coprolites, teeth of sharks, and reptilian bones						X[a]																																
Corbula nematophora Meek																																			X	X	X	
Exogyra columbella Meek																																	X	X	X	X		X
Exogyra sp. undetermined																														X								
Fish bones and scales	X[a]												X[a]																		X			X				
Globigerina bulloides D'Orbigny	X[a]		X																								X											
Globigerina sp. undetermined									X	X		X	X													X												
Helicoceras corrugatum Stanton																													?									
Helicoceras pariense (White)																									X													
Hypsodon audax Leidy													X	?		?																						
Inoceramus deformis Meek		X[a]																																				
Inoceramus (Haploscapha) grandis Conrad	X																																					
Inoceramus fragilis Hall and Meek				X	?		X	X	X		X			X	X																							
Inoceramus n. sp., related to I. fragilis																															X							
Inoceramus labiatus Schlotheim																					X	X	X	X	X	X	X		X									
Inoceramus sp., fragments of large shells									X																													
Inoceramus sp., fragments										X		X								X																X		
Mactra sp. undetermined																																				X		
Metoicoceras whitei Hyatt																								X		X												
Mollusk borings in fossil wood, indeterminate																			X																			
Ostrea congesta Conrad	X	X[a]							?	X	?	X								X							?											
Ostrea sp., a small, simple species							?																					X			X							
Ostrea sp., undetermined																														X		X						
Prionocyclus aff. P. wyomingensis Meek					X[a]																																	
Prionotropis woolgari Mantell							X		X			X	?		X	X	?	X																				
Prionotropis n. sp. (a)																															X							
Prionotropis n. sp. (b.) fragment																										X												
Puzosia n. sp. aff. P. gaudama Forbes																							X															
Scaphites sp. indeterminable							X																															
Serpula tenuicarinata Meek and Hayden									X																													
Textularia sp	X[a]		X							X			X																									
Turritella whitei Stanton																																				X		

[a] Field identifications.

10-6048

MARLAND OIL COMPANY OF COLORADO

MARLAND OIL COMPANY OF COLORADO

State Geological Survey of Kansas
Illustrations for Bulletin 10
Geology of Russell County, Kansas

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